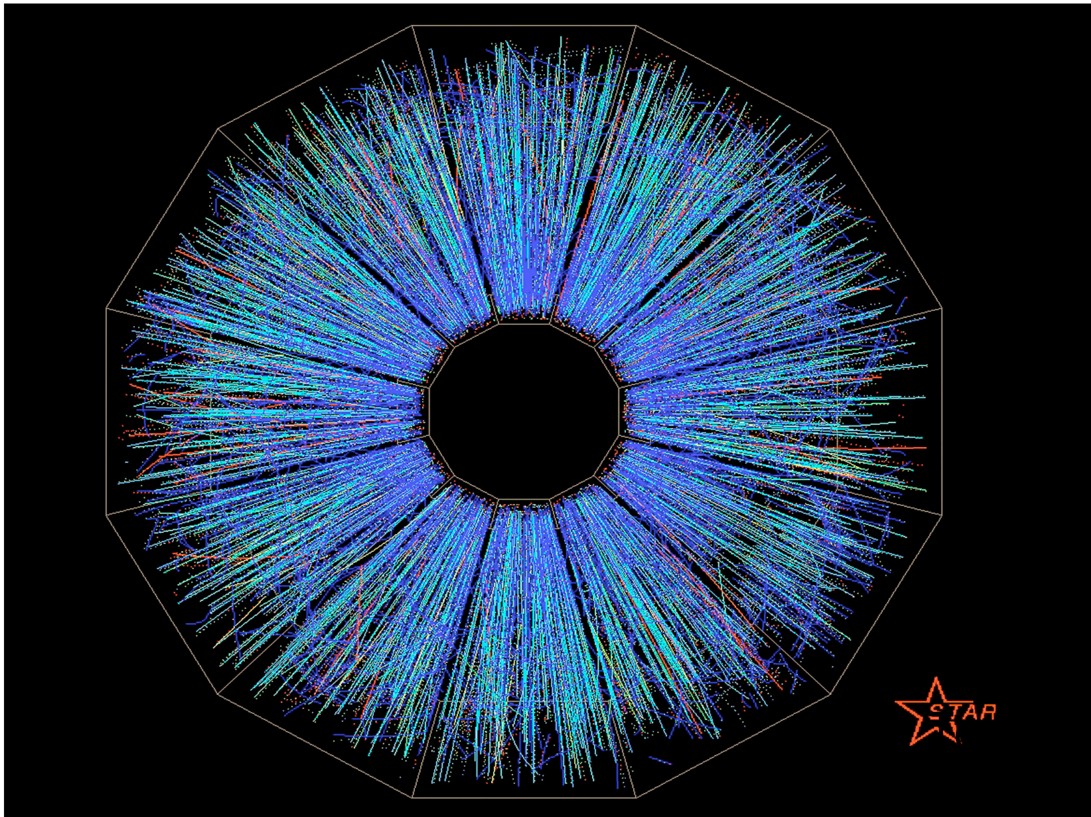
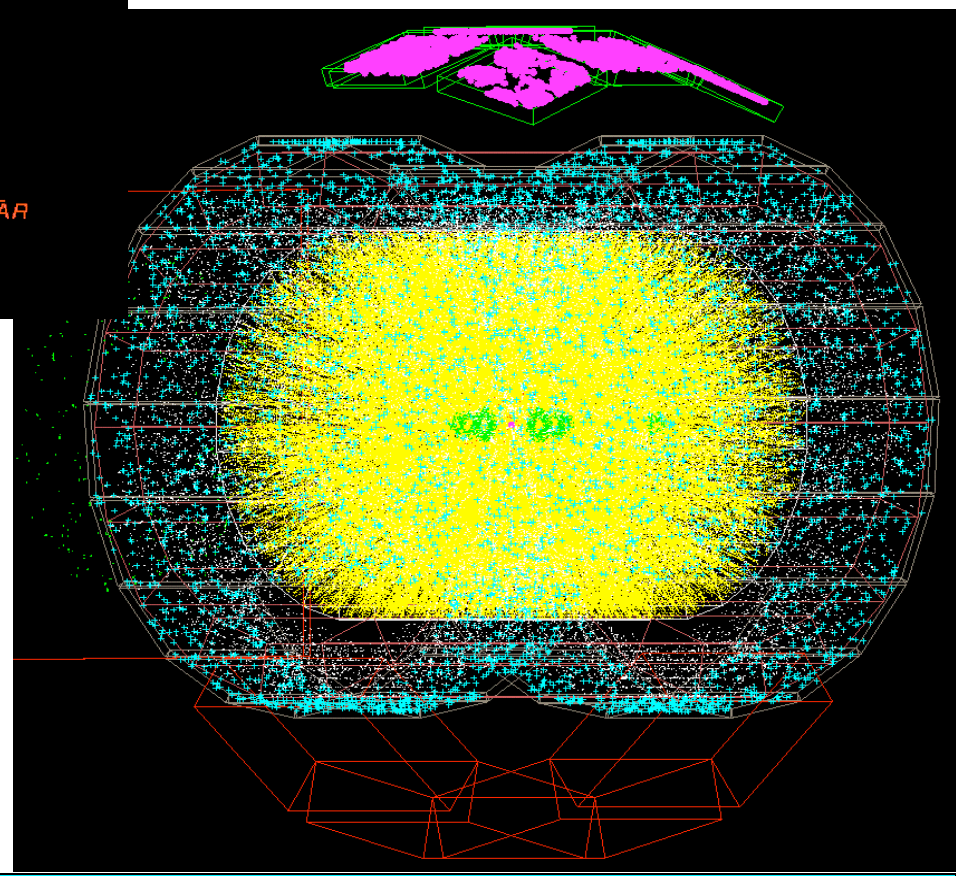
The ALICE-TOF system

1. Quick overview of the TOF system that we are building
2. The Multigap Resistive Plate Chamber
   -what is it?
3. Difference in operation of 2 mm gap and 250 micron gap
4. Summary



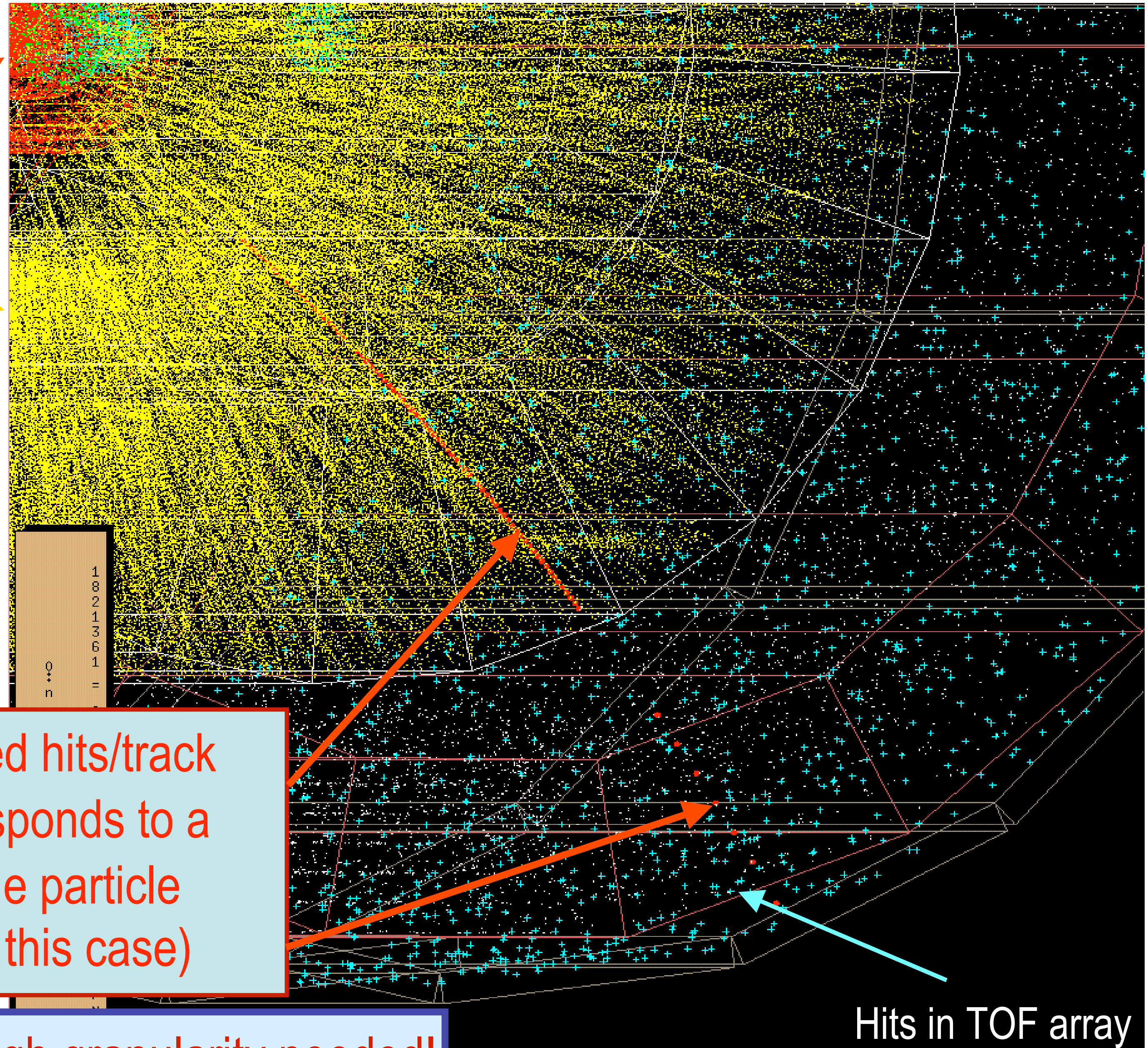
Heavy ion collisions produce many particles... but only 1 central collision every 250 □s.



Question: How do we make sense of this?
Answer: Identify each particle - or at least as many as possible.

Hits in inner tracker

TPC hits



The red hits/track corresponds to a single particle (□ in this case)

TOF with very high granularity needed!

What is needed?

Large array to cover whole ALICE barrel - 160 m^2

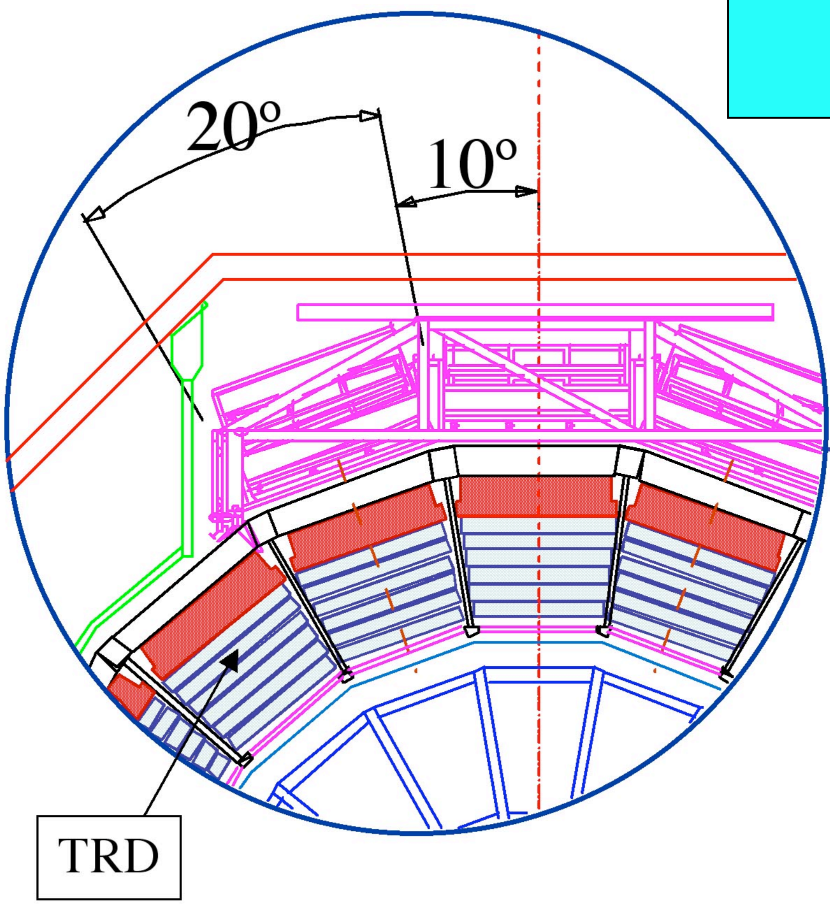
100 ps time resolution

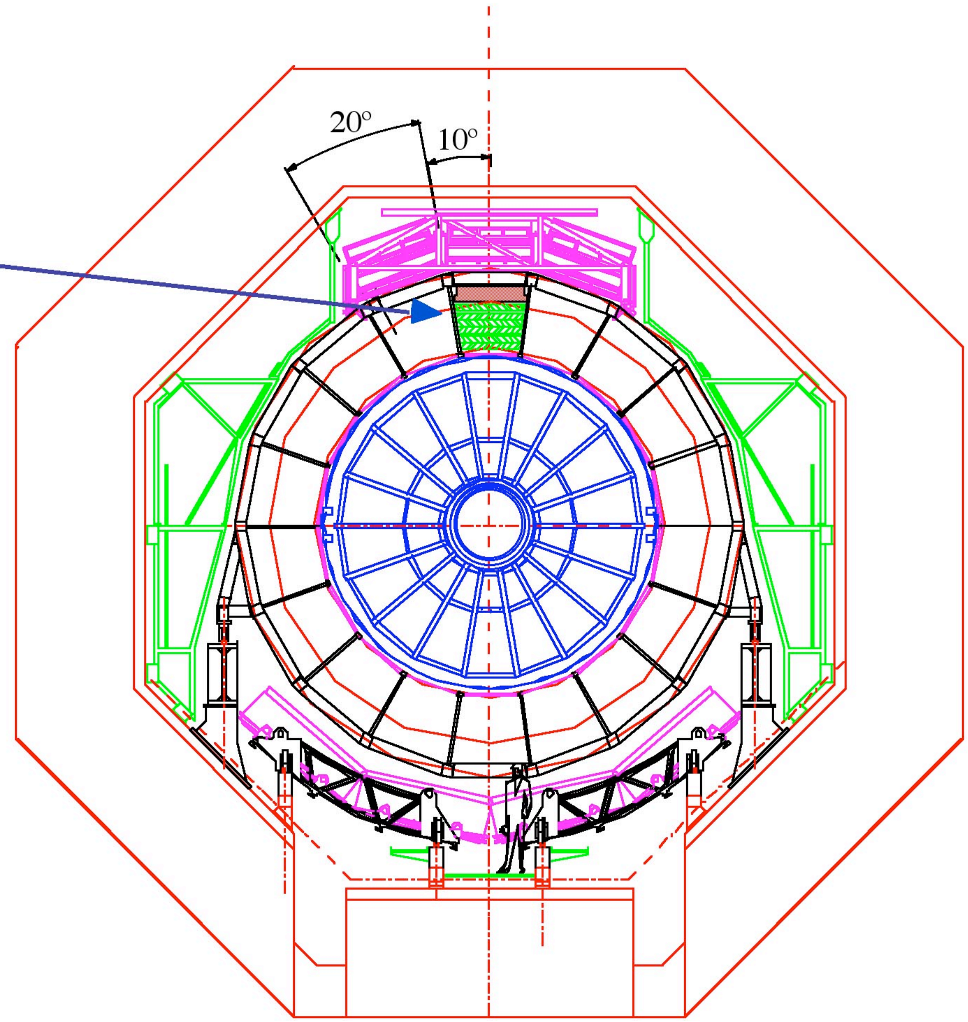
Highly segmented - 160,000 channels of size 2.5 x 3.5 cm^2

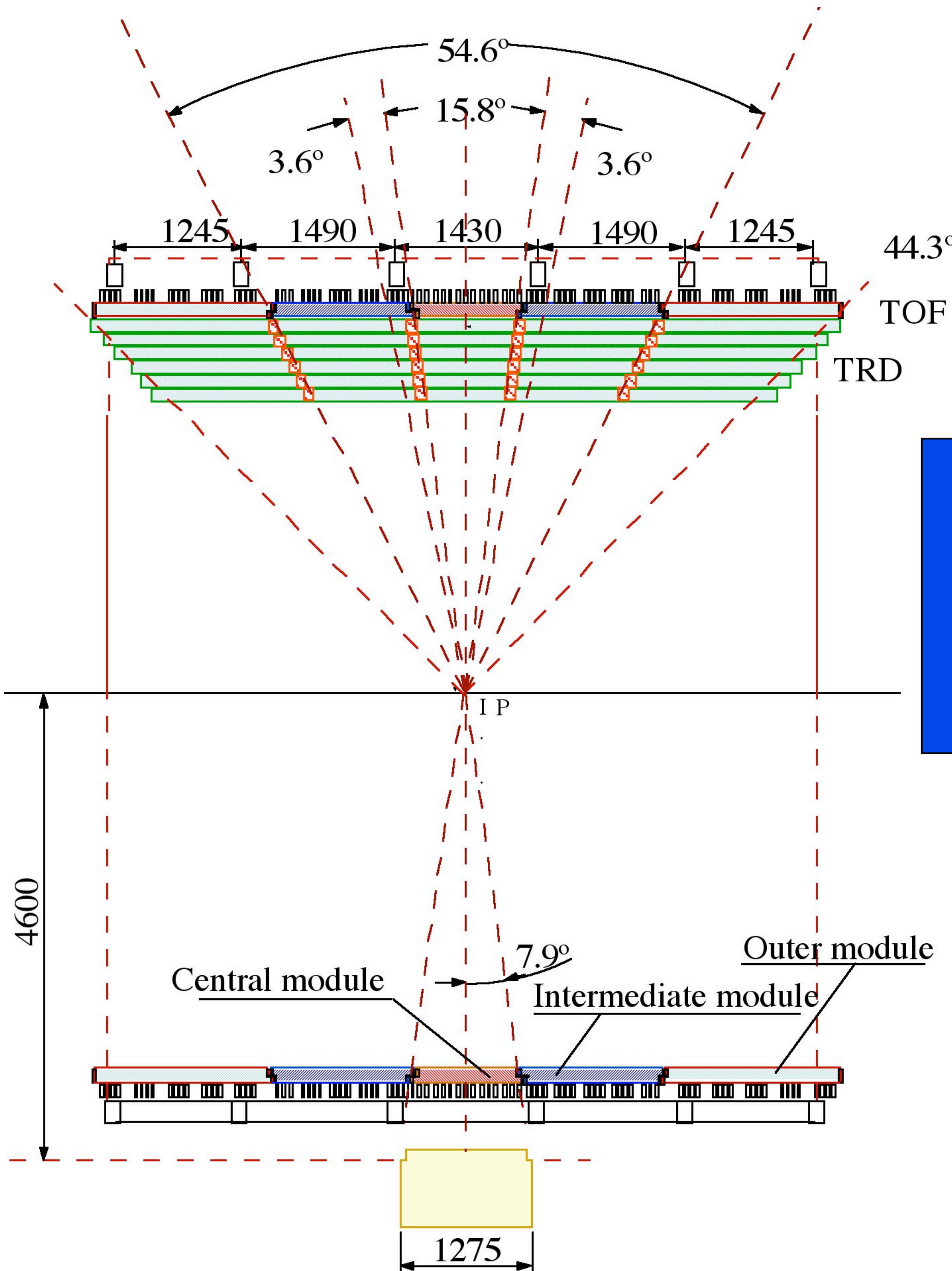
Occupancy ~ 12% (if 8,000 particles produced per unit of rapidity)

GASEOUS DETECTOR IS THE ONLY CHOICE

CROSS SECTION OF ALICE EXPERIMENT







r-z view of ALICE

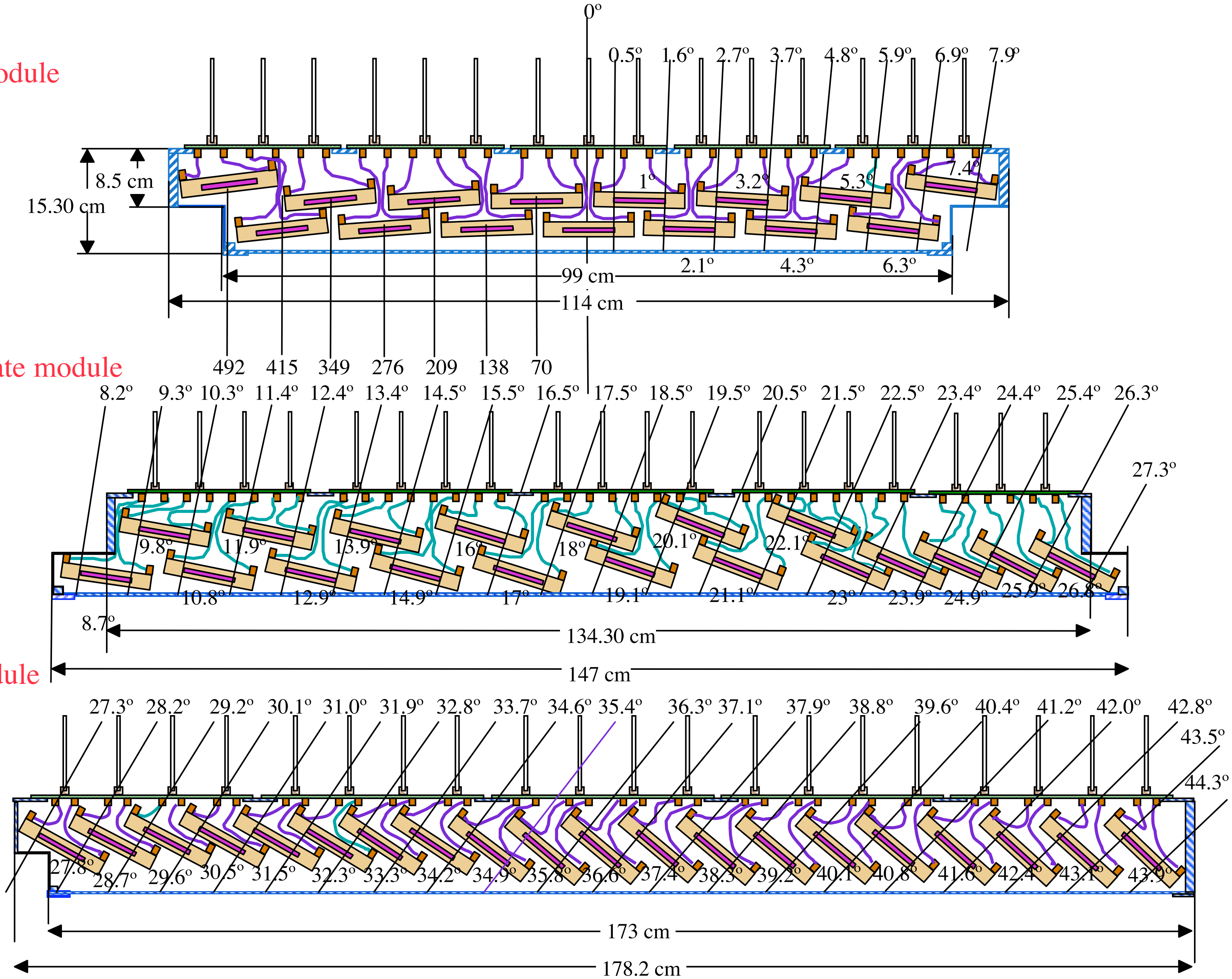
The TOF is divided into 5 modules along the length

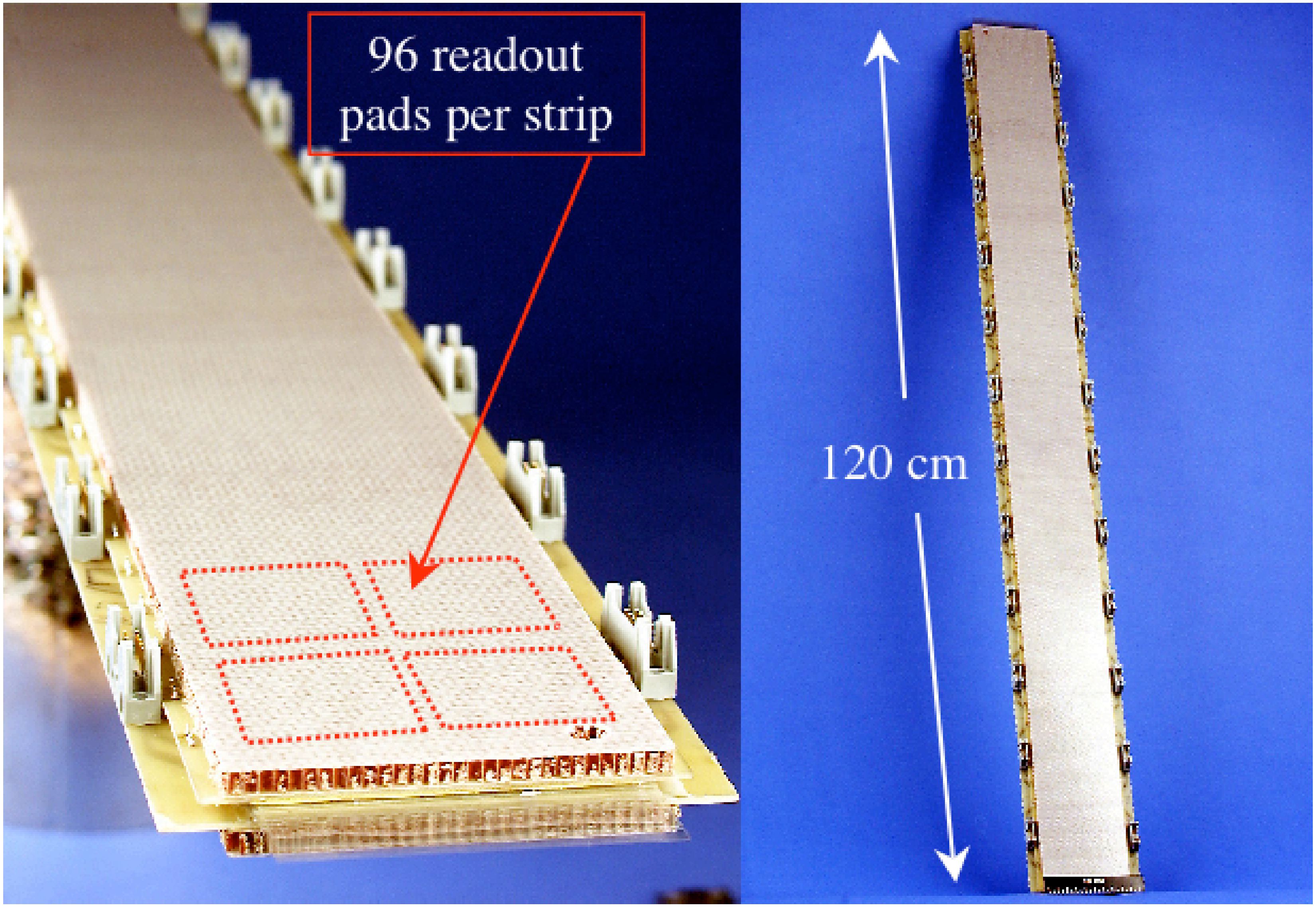
ALICE TOF MODULES - STRIPS TILTED TO FACE INTERACTION POINT

Central module

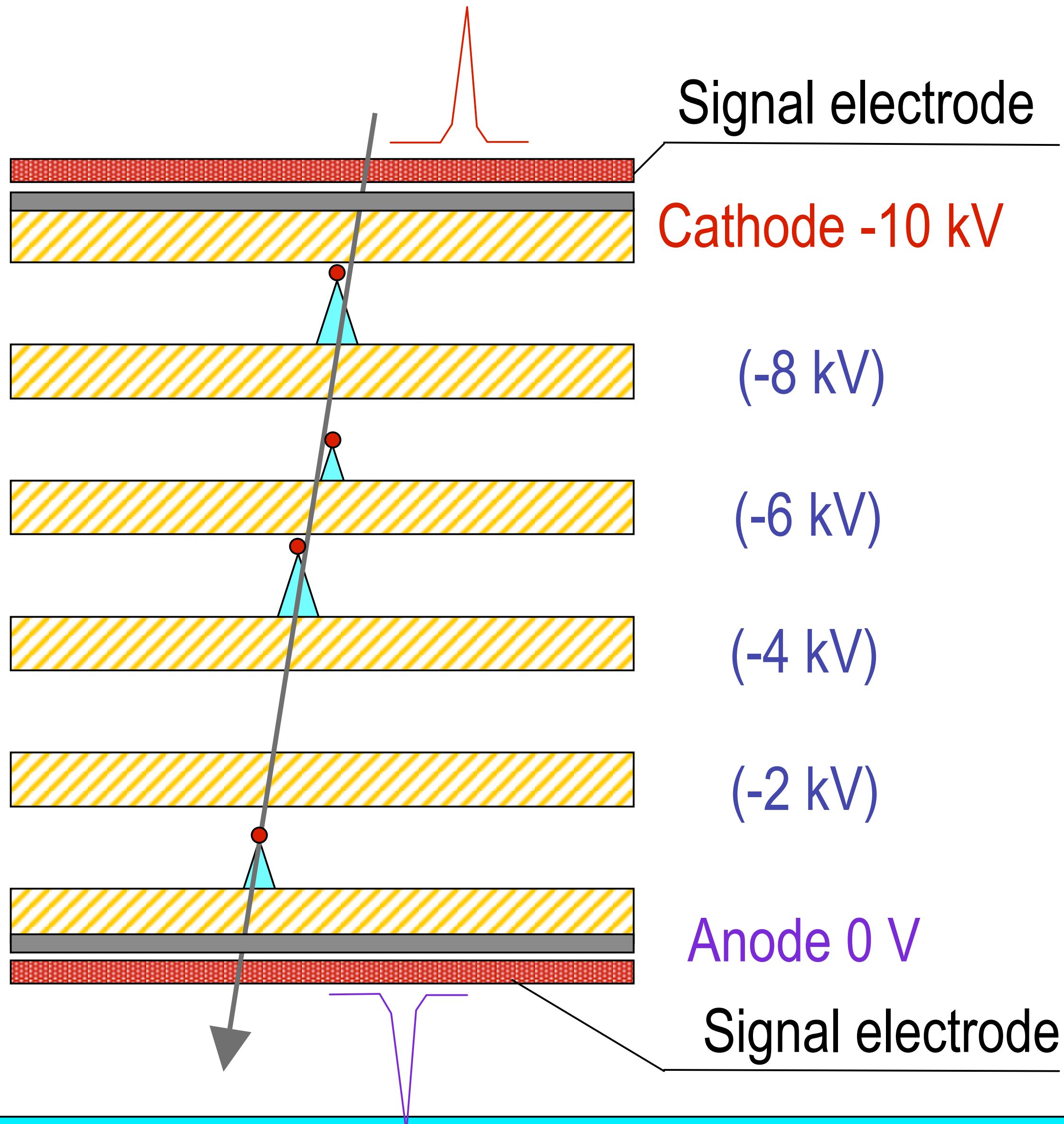
Intermediate module

Outer module




96 readout
pads per strip
120 cm

1996: LAA MULTIGAP RESISTIVE PLATE CHAMBER
(R&D project to improve Resistive Plate Chambers)

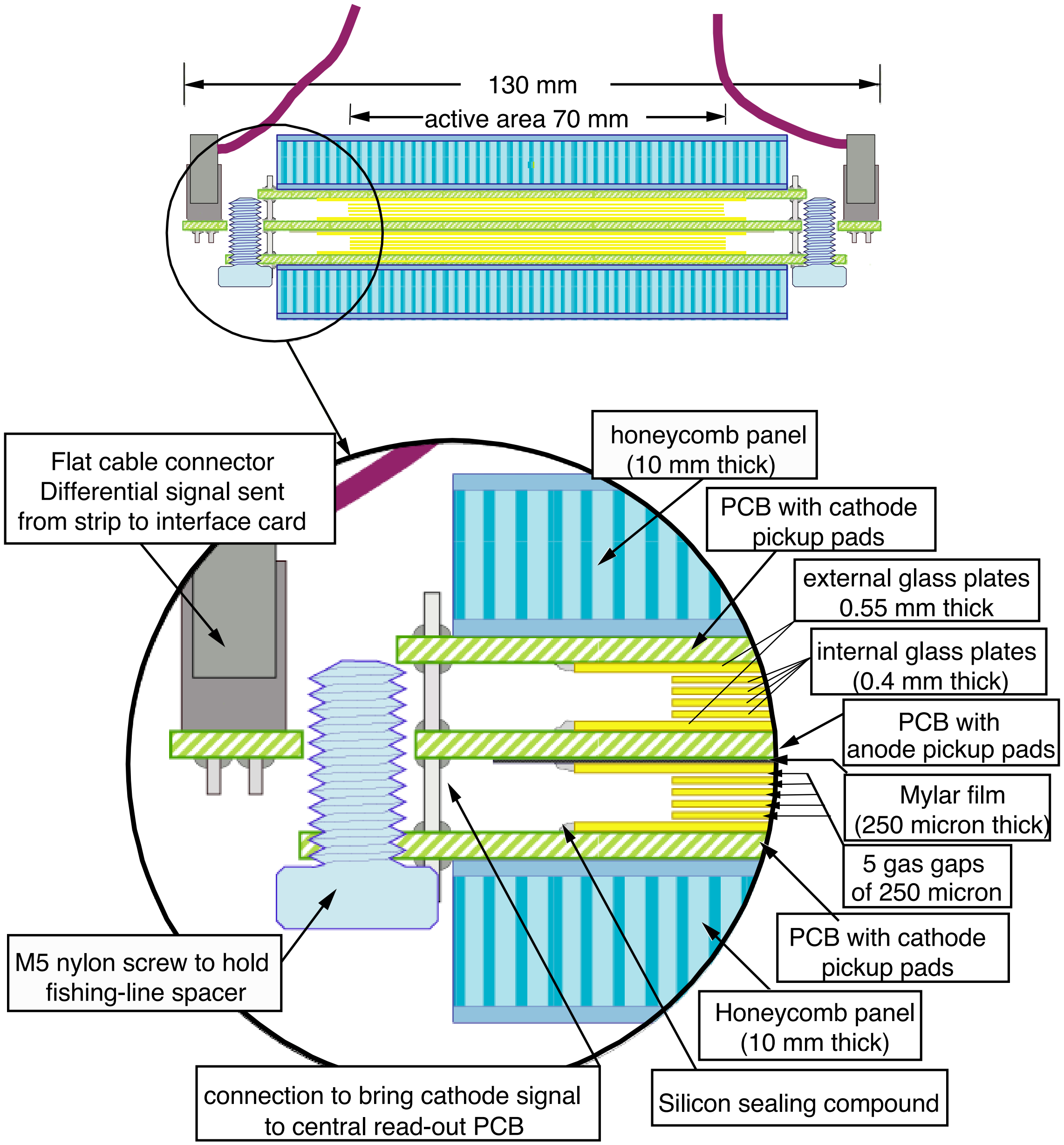


Stack of equally-spaced resistive plates with voltage applied to external surfaces (all internal plates electrically floating)

Pickup electrodes on external surfaces (resistive plates transparent to fast signal)

Internal plates take correct voltage - initially due to electrostatics but kept at correct voltage by flow of electrons and positive ions - feedback principle that dictates equal gain in all gas gaps

ALICE TIME OF FLIGHT   MULTIGAP RESISTIVE PLATE CHAMBER



Double stack

- each stack has 5 gaps

(i.e. 10 gaps in total)

250 micron gaps with spacers made from fishing line

Resistive plates 'off-the-shelf' soda lime glass

400 micron internal glass

550 micron external glass

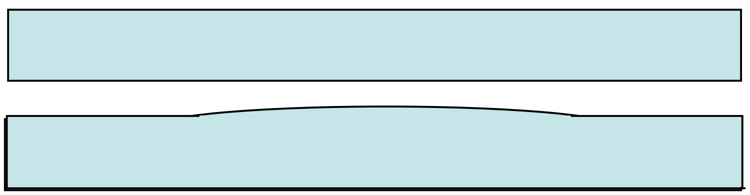
Resistive coating

5 MΩ /square

Good timing needs small gas gaps - this is the reason for gaps of 250 micron

Need a certain thickness of gas - so that we have something for through-going charged particles to ionise - this is the reason for the 10 gaps (2.5 mm total)

Gas gaps of small size need to be constructed with very tight mechanical tolerance to have uniform field

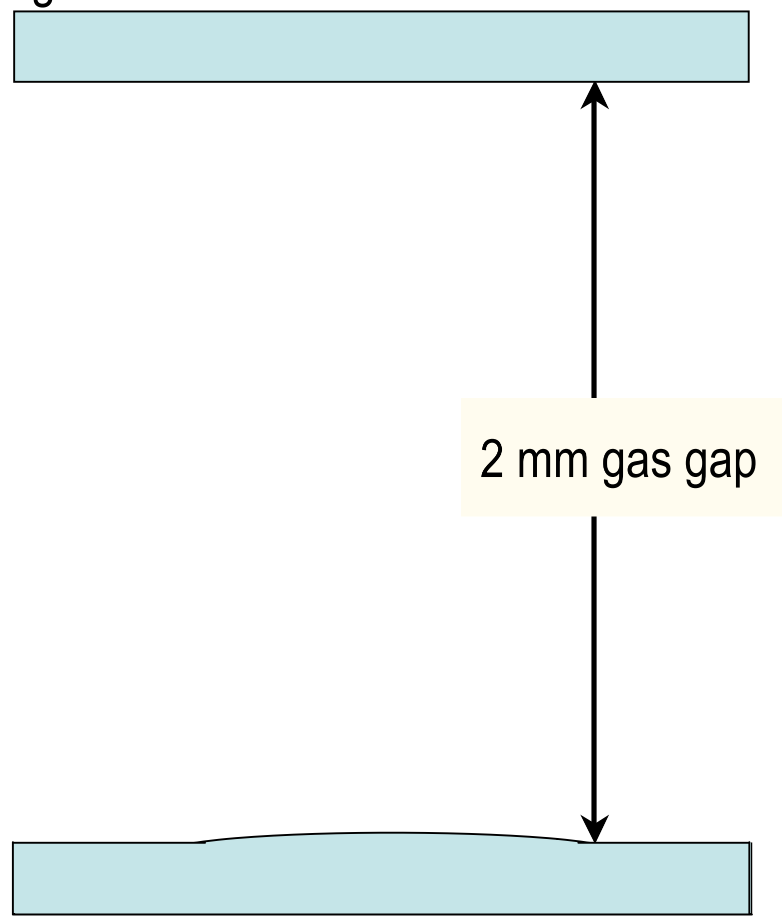


250 μm gas gap

25 μm bump 10% increase in E field

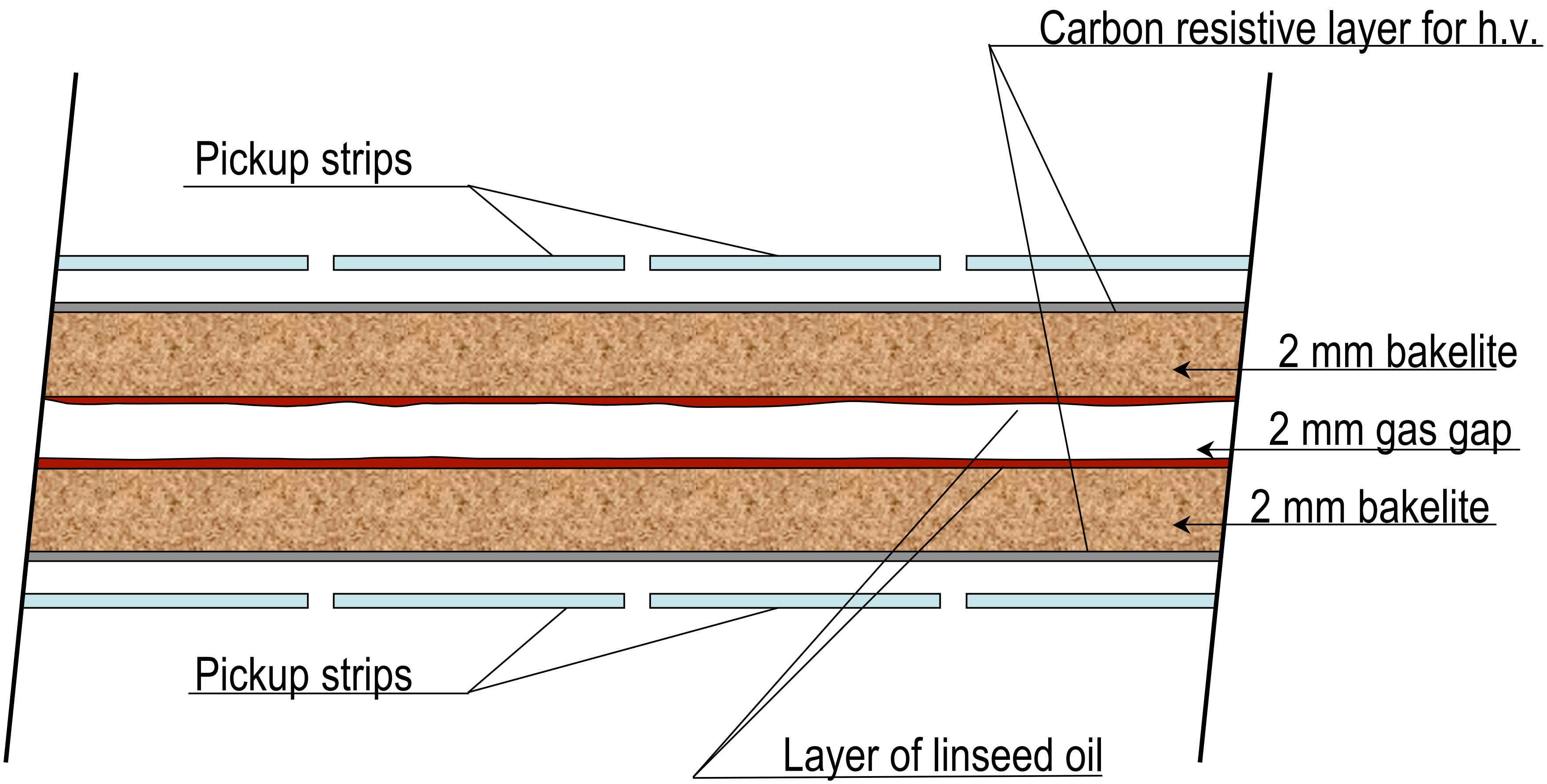
QUESTION : CAN WE BUILD 1500 m^2 OF GAP WITH ULTRA PRECISE TOLERANCE?

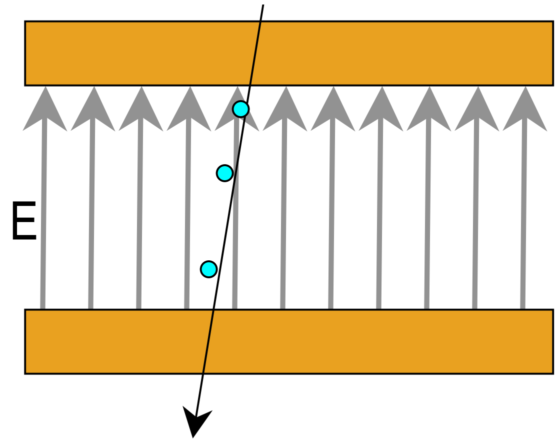
QUESTION : WHAT TOLERANCE IS NEEDED??



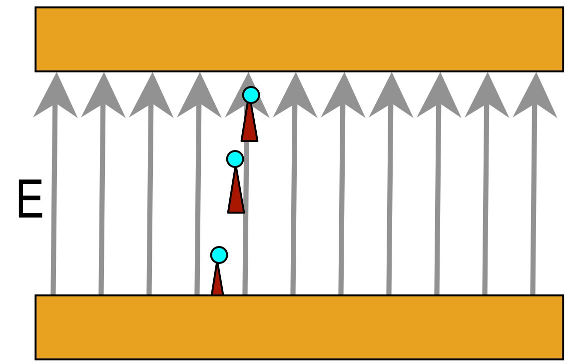
25 μm bump only 1% increase in E field

2 mm gap RPCs developed by Santonico in the 1980's



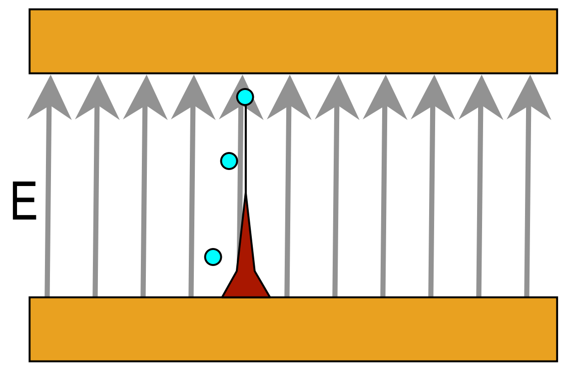


Through-going charged particle creates clusters of electrons and positive ions

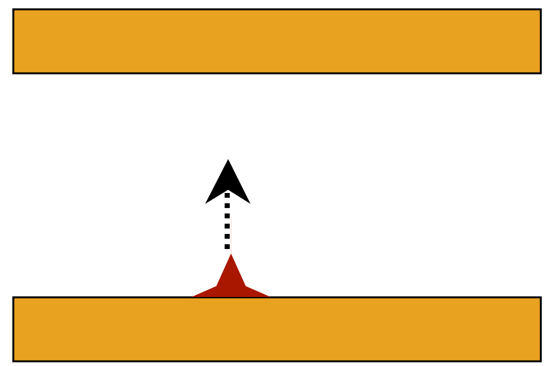


Electrons avalanche in high electric field

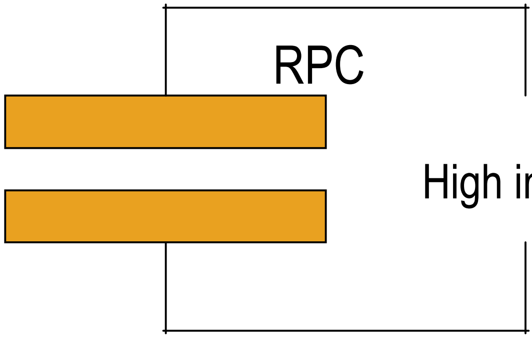
$N=N_o e^{\alpha x}$



In avalanche mode - only avalanches that start close to cathode grow big enough to induce signal in external electrodes



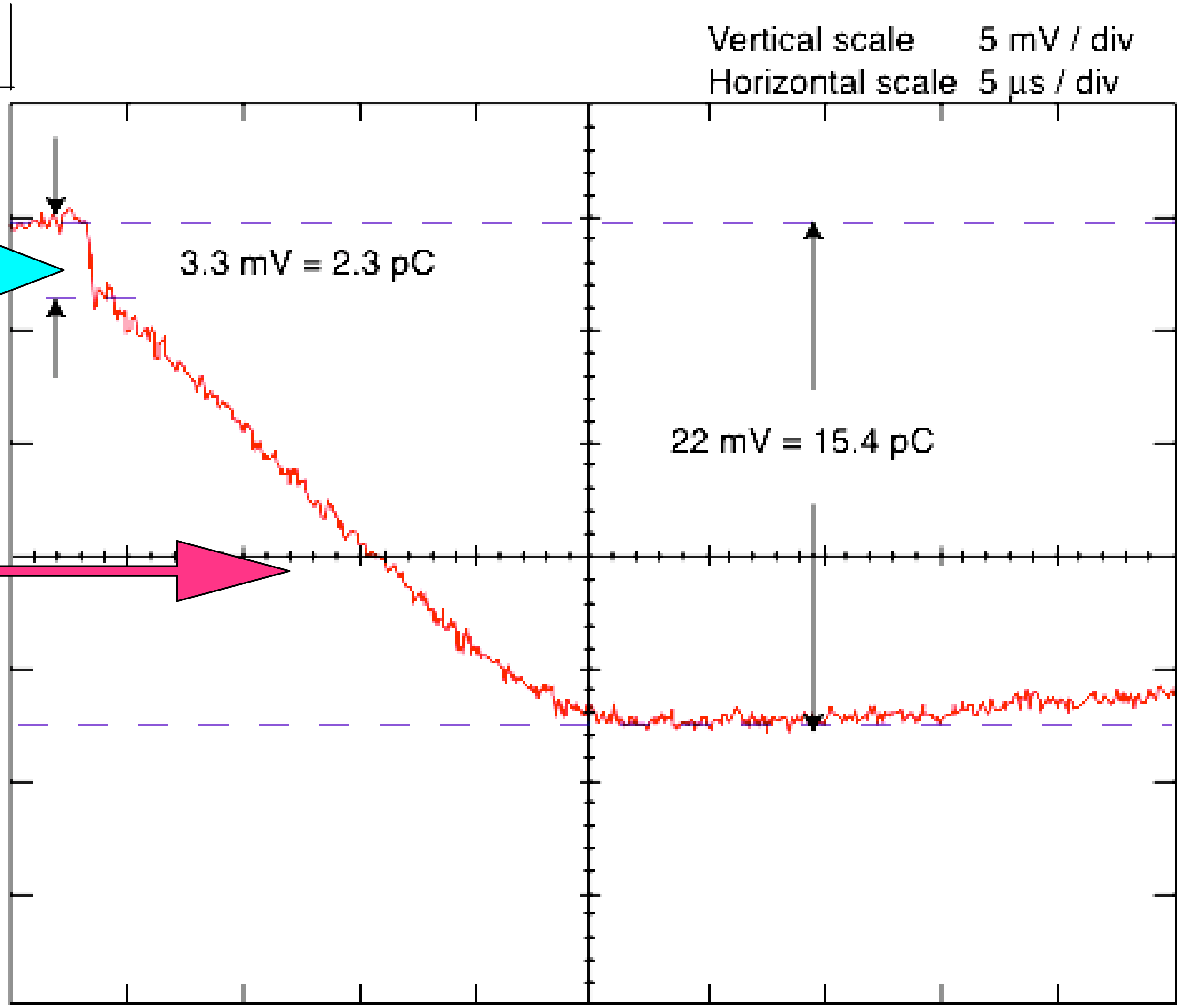
Cloud of positive ions (n.b. same number as electrons in avalanche) drift slowly to cathode (large distance therefore large signal)



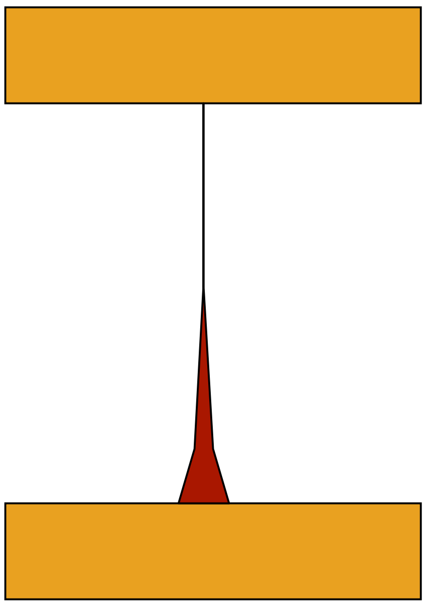
Can measure ratio of fast/total with oscilloscope

Fast signal: electrons move towards anode

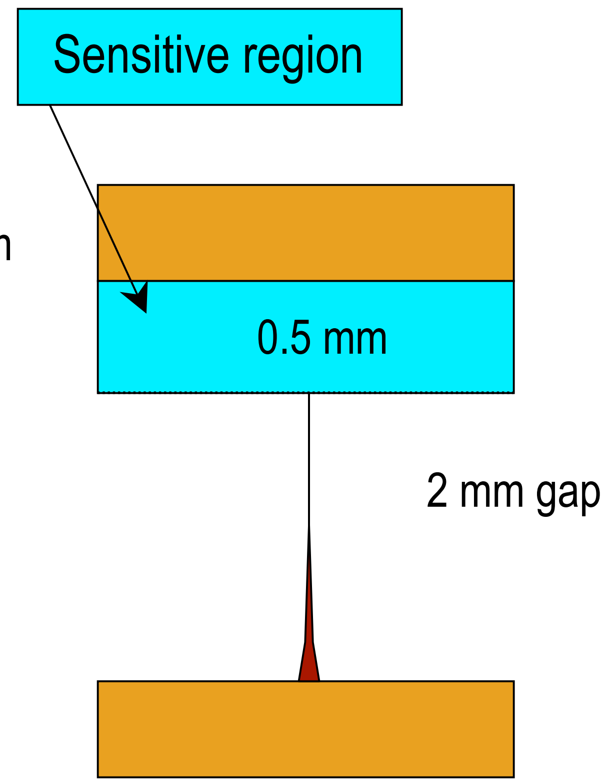
Slow signal: positive ion cloud moves away from anode



In the case of Townsend avalanche : one can calculate that the fast signal / total signal = 1/ αD
D is size of gap α is Townsend coefficient (only a small fraction of the total charge appears as a fast signal)



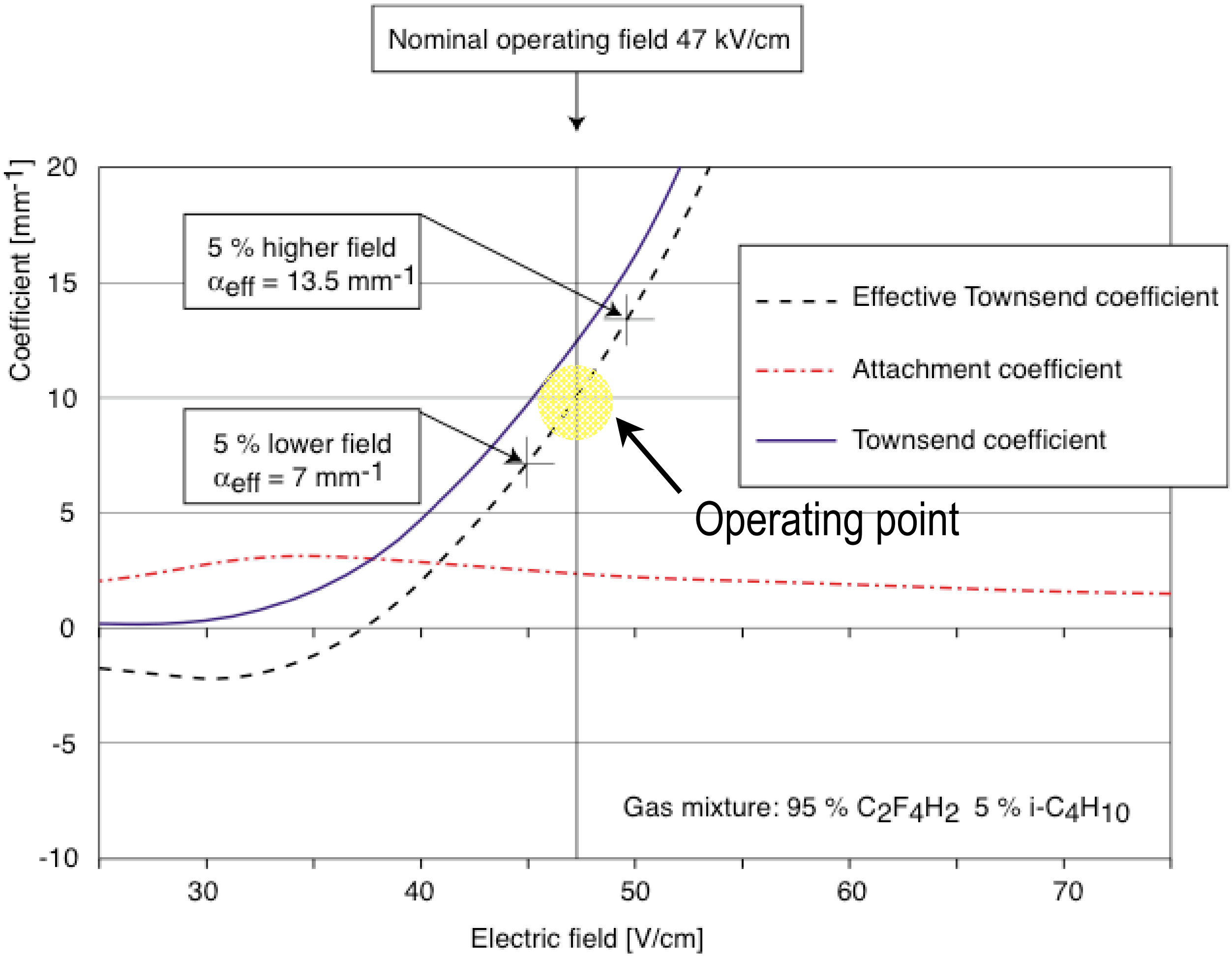
Set gas gain to be $10^8 = e^{\alpha D}$
for single electron crossing gap
(i.e αD ~18.5)
Fast signal
~ $10^8 * 1.6\ 10^{-19}$ (1/18.5)
~ 900 fC



Avalanche starting 0.5 mm away from cathode gives fast signal of ~ 9 fC (low threshold for large area RPCs)

So need heavy gas (such as $C_2F_4H_2$) to produce primary ionisation close to cathode (7.5 clusters/mm ~ 97.5 % max efficiency)

Use MAGBOLTZ to get value of □ and dependence on applied voltage



$\square_{effective}$ = □□□

At applied voltage of 9.4 kV
$\square_{eff}$ = 10 gas gain e□D = 5 10^8

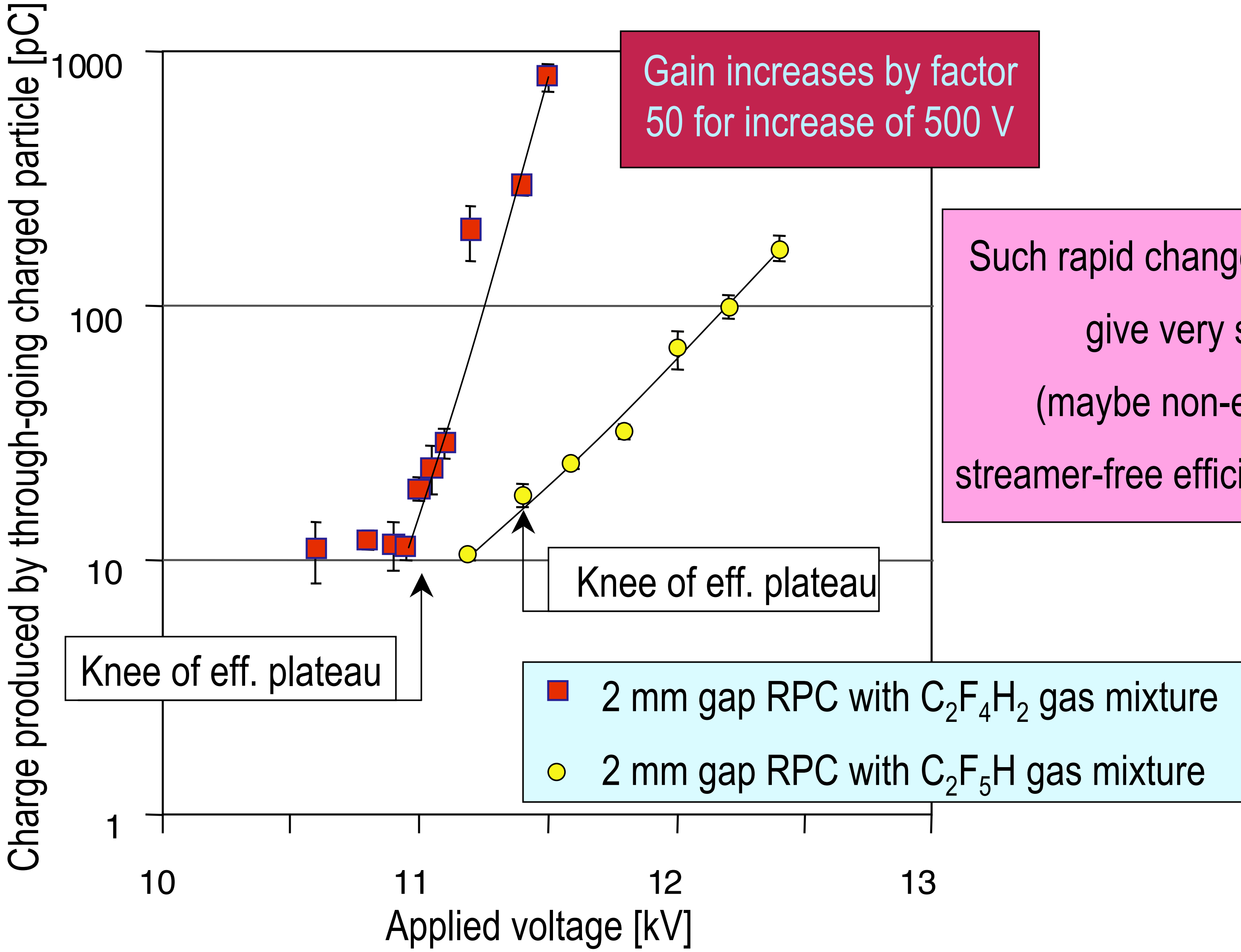
Increase applied voltage by 100 V (i.e. 1 %)
$\square_{eff}$ =10.7 gas gain e□D = 2 10^9
(factor 4 increase)

Similarly decrease by 100 V (1 %)
□eff =9.4 gas gain e□D = 1 10^8
(factor 4 increase)

- Big variation in gain with small change in field
- Very short streamer-free plateau
- Very sensitive to change in gap size
- 20 micron is 1% change of field

It is clear that this device is in trouble… very difficult to find stable operating point - however resistivity of bakelite helps

Measure TOTAL charge of 2 mm RPC



Such rapid change in gain will give very short (maybe non-existent) streamer-free efficiency plateau

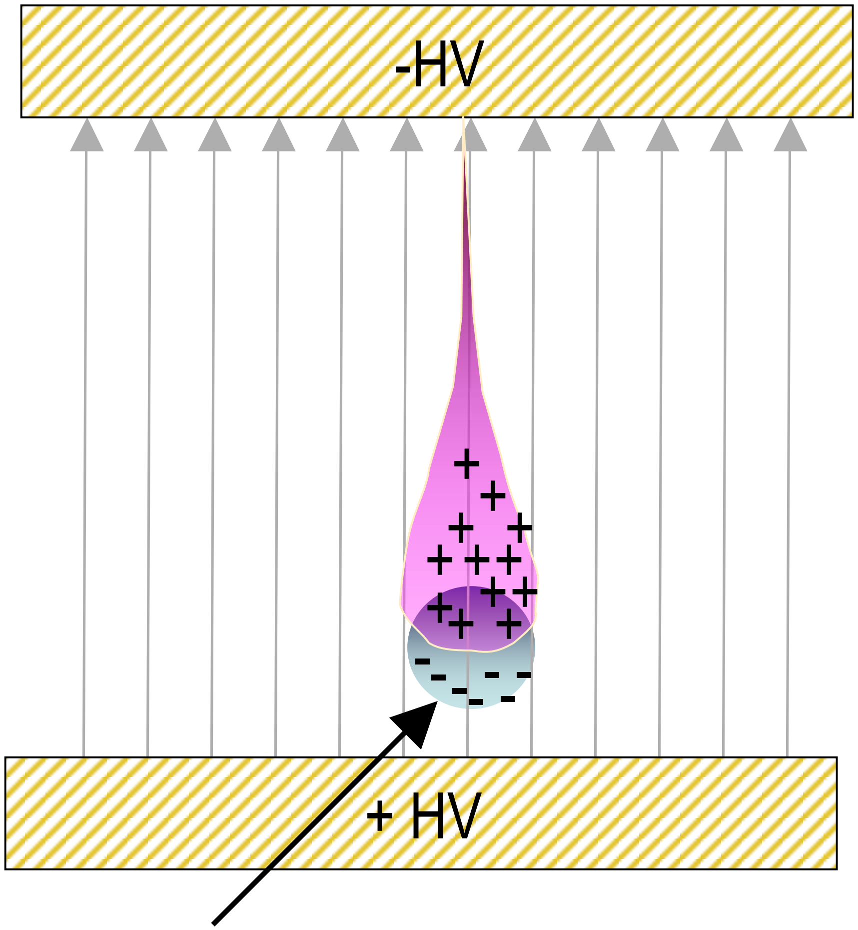
We have seen that 2 mm RPC has large variations in gain for small changes in voltage and gap width.

WHAT ABOUT THE ALICE TOF MRPCs?

Question: Surely gaps of 250 micron are going to be even more sensitive to changes in voltage and gap width?

Answer: avalanche growth in small gas gaps dominated by space charge effects

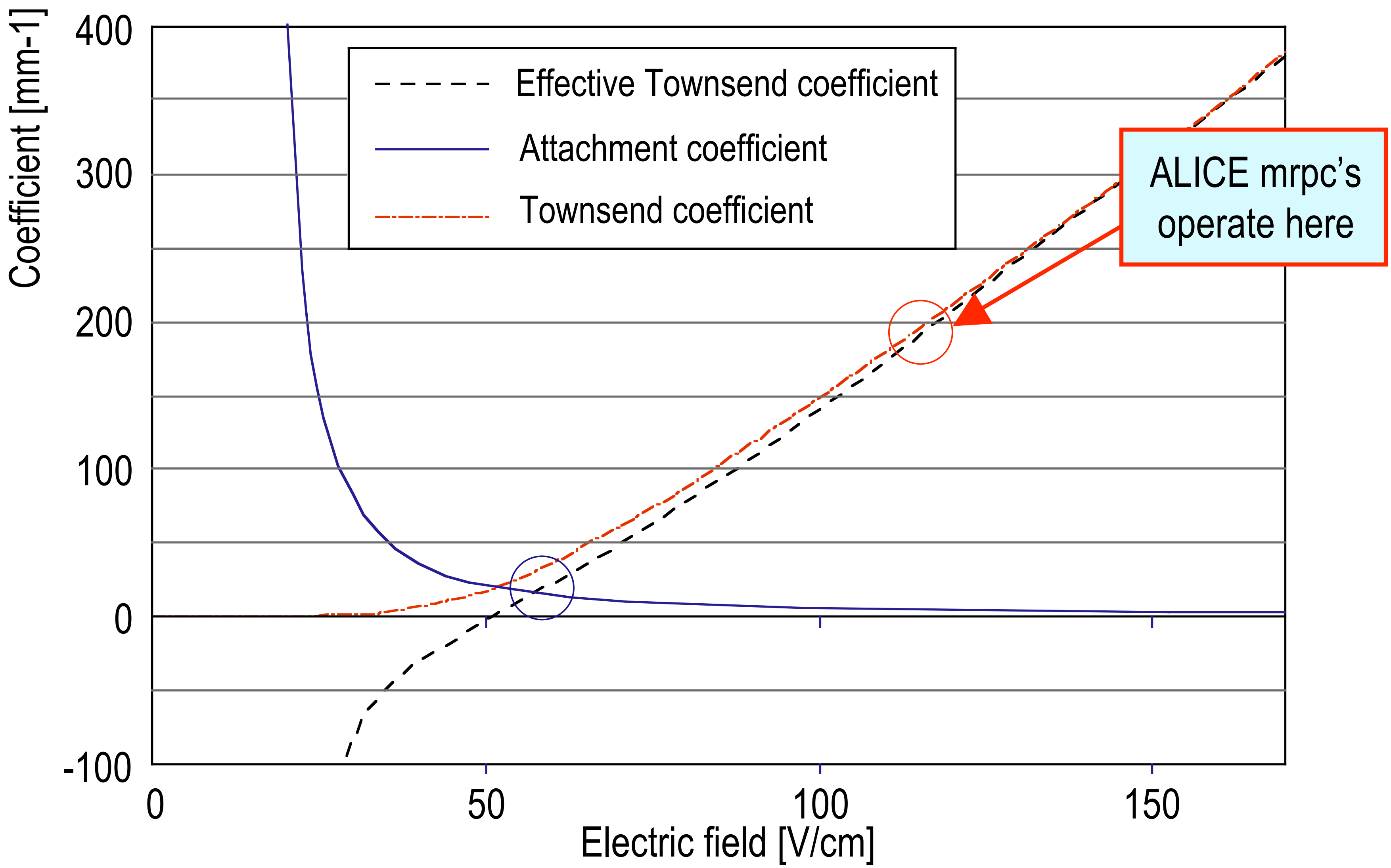
Growth of avalanche limited by space charge of positive ions



Low field region due to space charge

Every time an ionising collision creates an electron, there is also a positive ion created. Since the positive ion is heavy - it is stationary in time scale of avalanche formation. The charge of these positive ions reduces the electric field seen by the electrons in the 'head' of the avalanche. i.e. Gas gain is reduced - so avalanche grows to certain size and then growth slows down.

Magboltz output for 90% $C_2F_4H_2$, 5% SF_6 and 5% i-C_4H_{10}

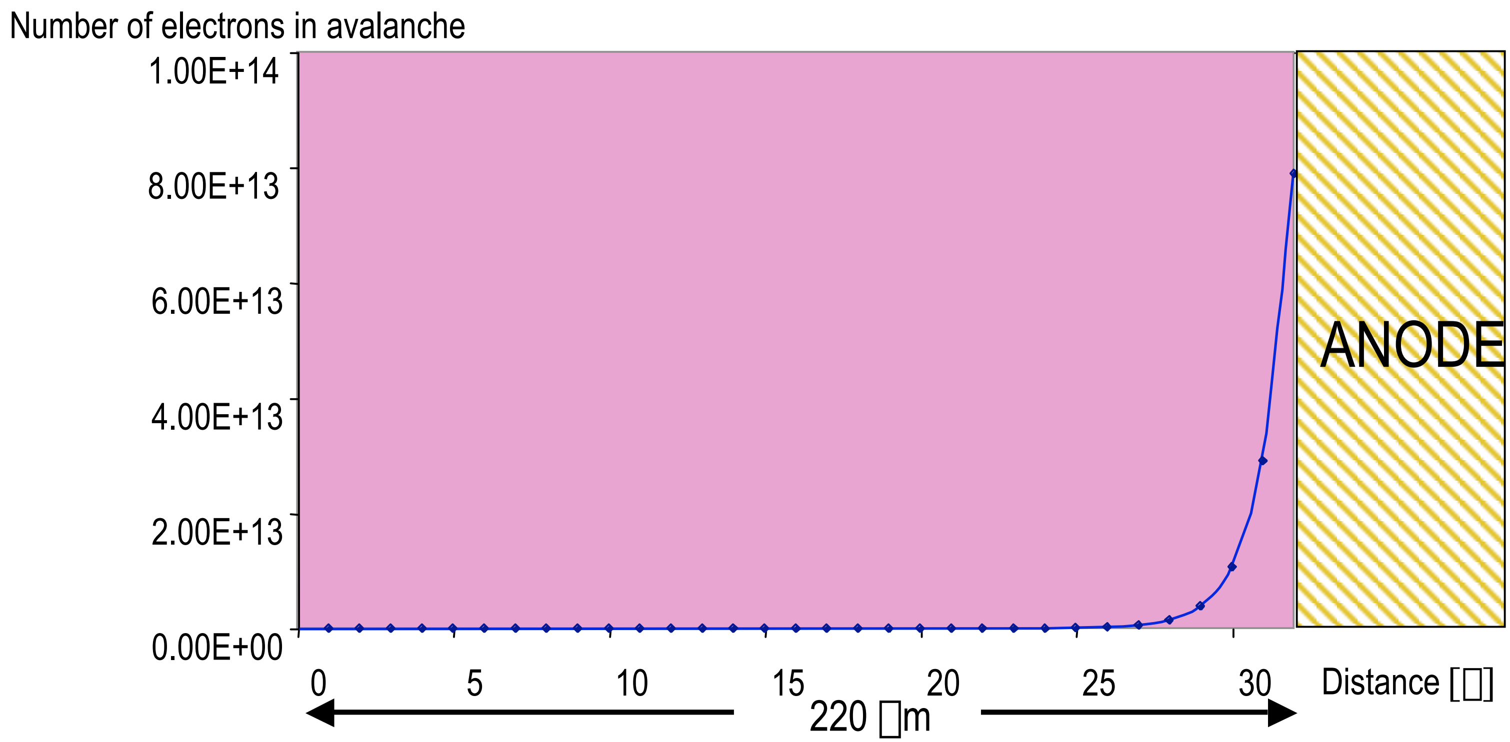


Use MAGBOLTZ program to predict Townsend coefficient and attachment coefficient in gas mixture 90% $C_2F_4H_2$, 5% iso-C_4H_{10} and 5% SF_6.

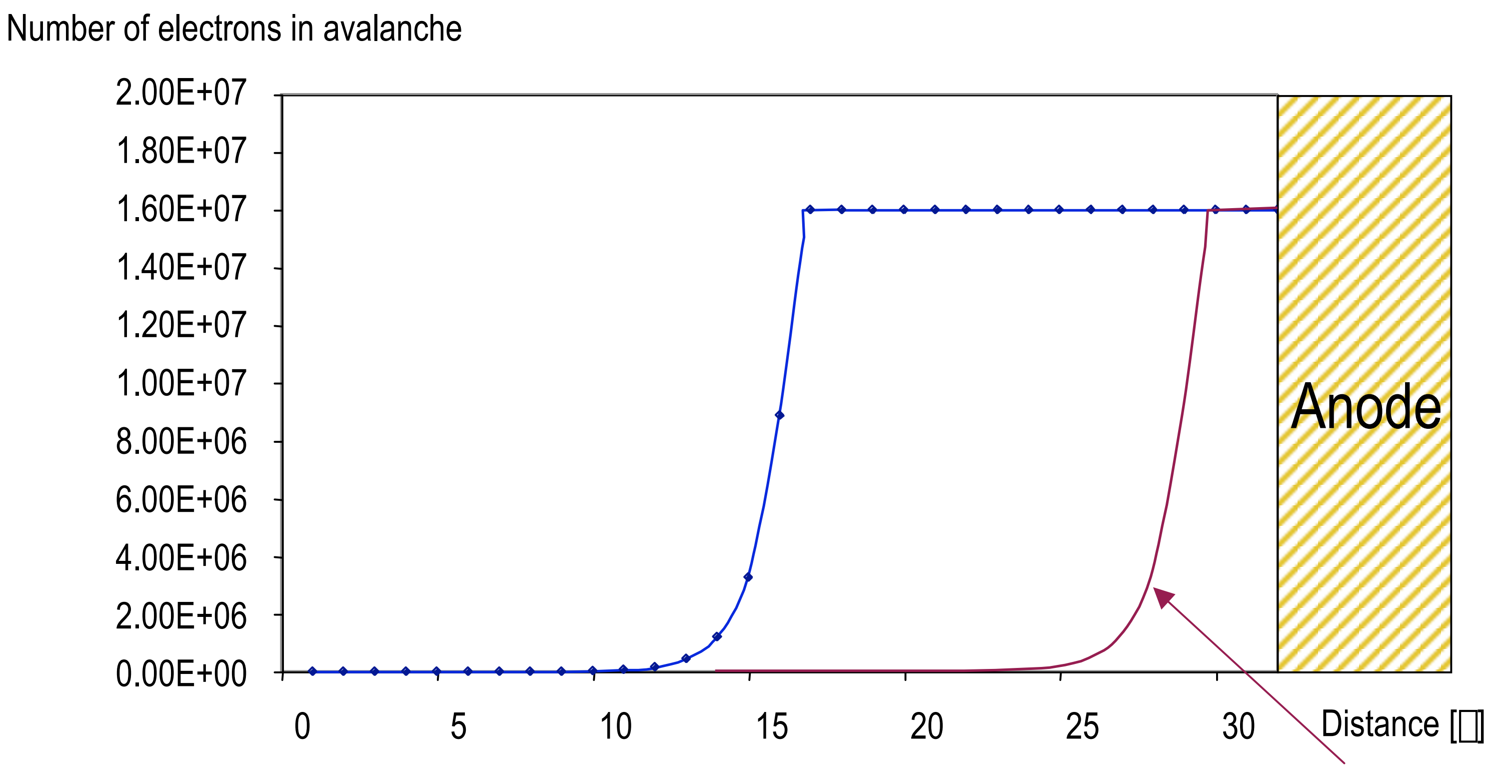
Result □ = 173.4 mm^{-1} and □ = 5.8 mm^{-1} for a 220 micron gap MRPC

i.e. □ = 6 □m

Single electron avalanching across 220 □m gap would produce ~10^{14} electrons !



Add 'space charge' limitation as saturation at 1.6 10^7 electrons



Question: can we believe that we are really working with such high Townsend coefficient?

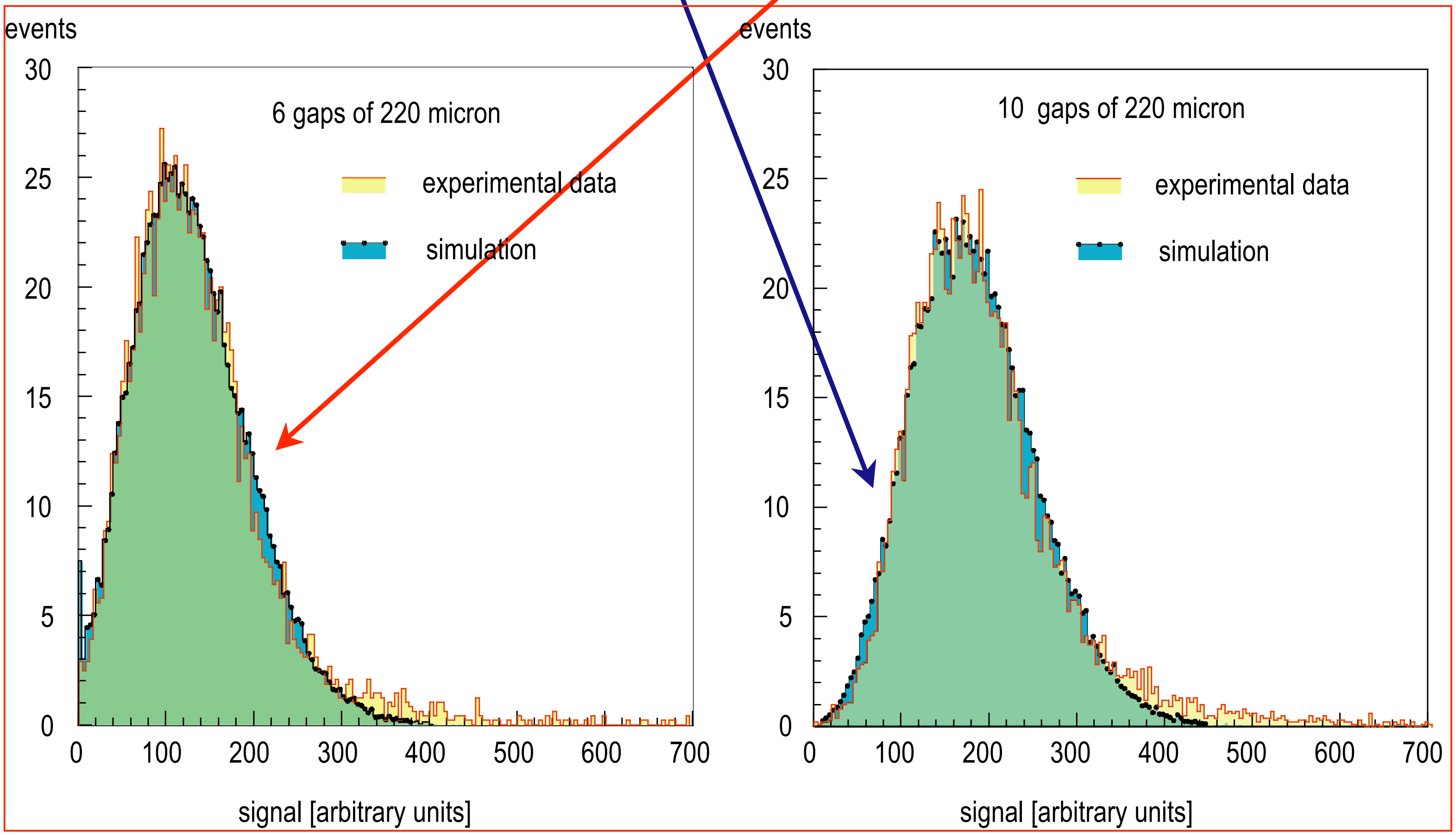
Even avalanches that start half way across gap can produce detectable signals

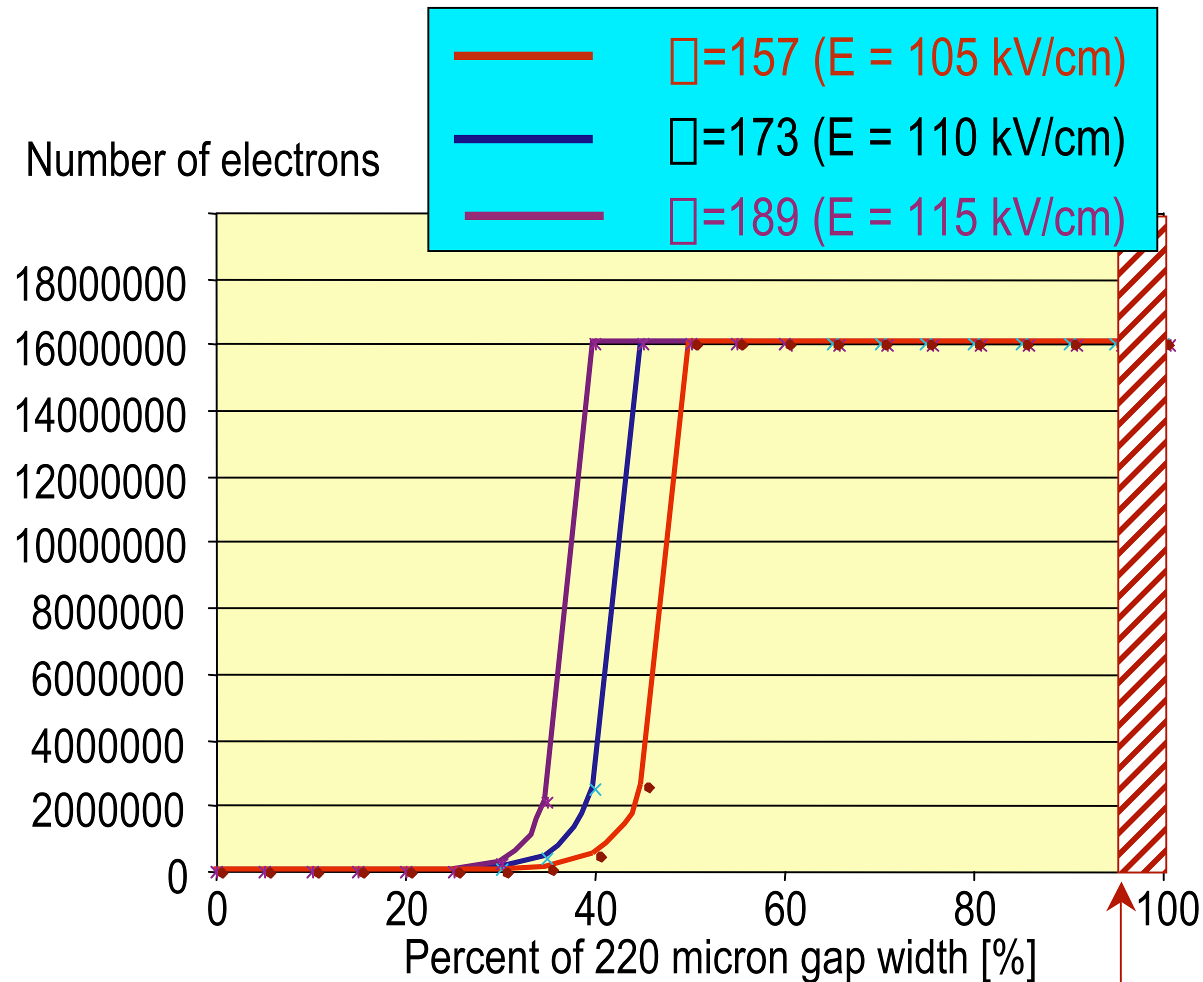
A. Very high efficiency (99.98 %) needs 9 independent clusters. Expect 7.5clusters/mm therefore with 10 gaps of 250 micron - there are 19 clusters in gas… therefore need 9/19 avalanches to give detectable signal i.e. avalanches starting halfway across gap have to give detectable signals

Shape of spectrum at low signals very dependent on value of (Townsend coefficient)

High part of spectrum depends on value of saturation (1.6 10^7 electrons)

B. Agreement between data and simulation





Vary applied voltage by ±5 %

Example: if voltage fixed but gap size reduced by 5% E□field 5% higher (avalanche follows purple line - but gap now ends at 95% of gap width

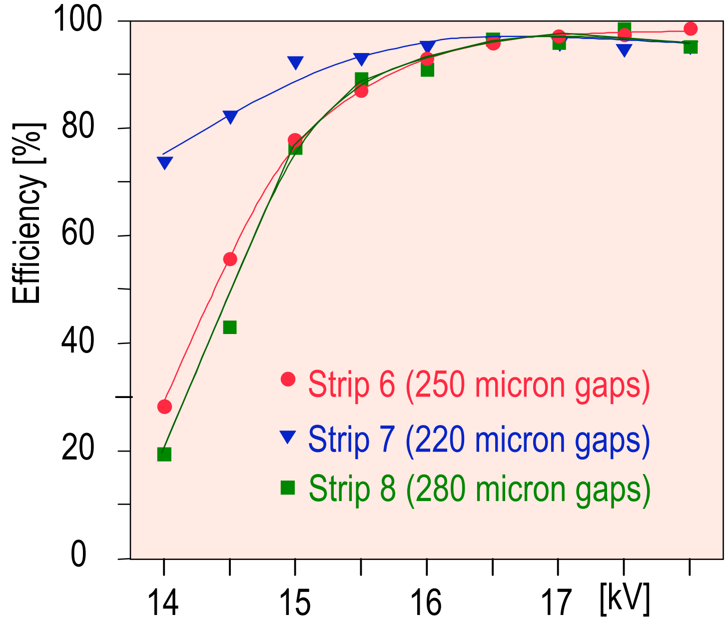
If the 5% change in electric field caused by gas gap size changing by 5% then effect shown above almost completely cancels !

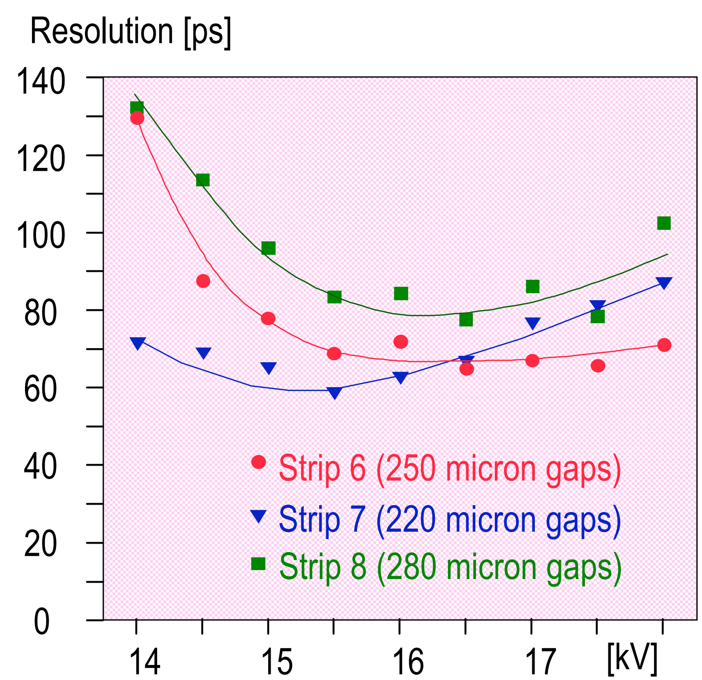
NON CRITICAL GAP TOLERANCE FOR GAS GAIN…

Note: fast signal / total signal should be much larger than for Townsend type avalanche

Tested 3 chambers with different sized gaps:

strip 6 - 6 gaps of 250 micron
strip 7 - 6 gaps of 220 micron
strip 8 - 6 gaps of 280 micron

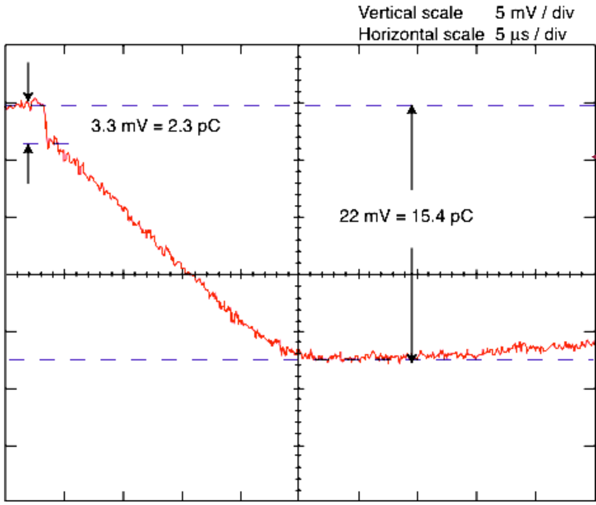




Huge change in gap size
 small change in operating voltage.
Large 'plateau' region where efficiency high, time resolution excellent and gap can vary by ± 30 m

Thus device with this excellent time resolution can be built with very 'relaxed' mechanical tolerances

What happens fast/total charge in the case of the MRPC?



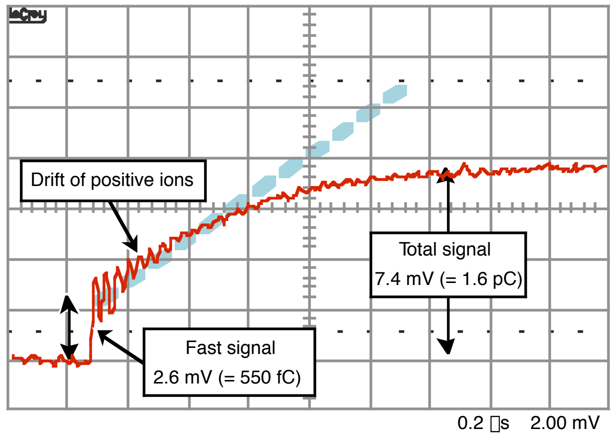
Reminder: 2 mm gap
Long linear ramp
Ratio fast/total is low

MRPC

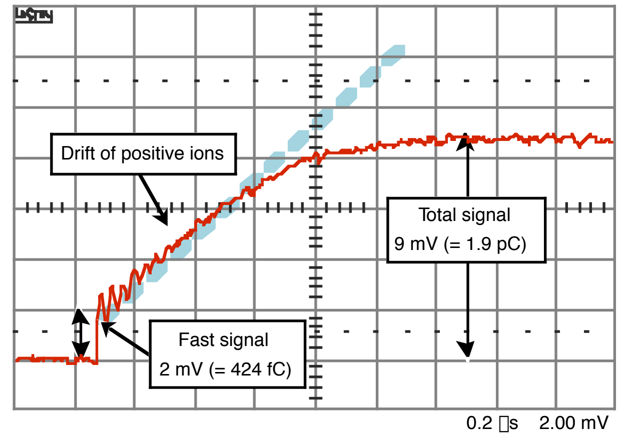
Non-linear ramp (positive ions not concentrated at a single position close to anode)

Fast/total large

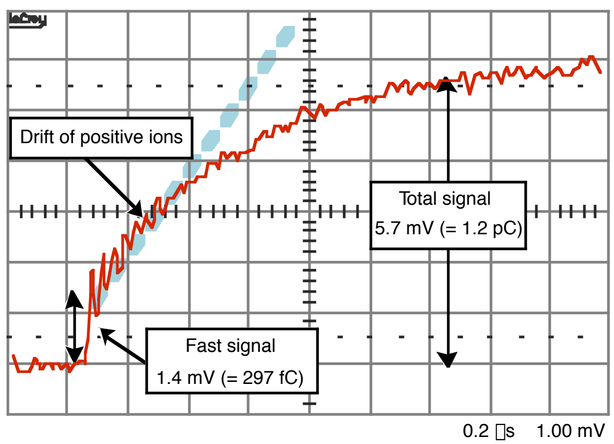
Avalanche signals: 10 gap double stack MRPC (250 micron gap) H.V. = 12.5 kV



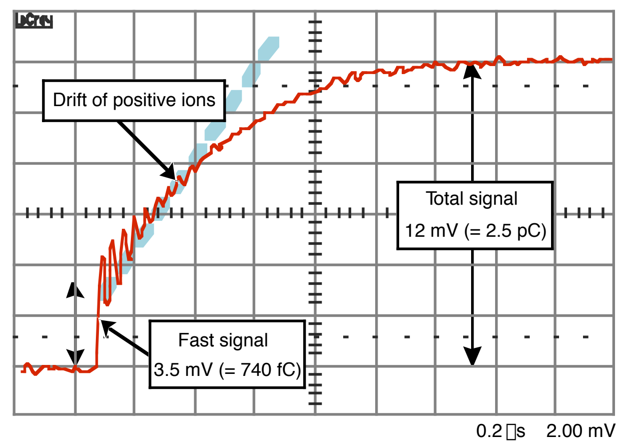
Ratio of fast signal/Total = 0.55/1.6 = 34 %



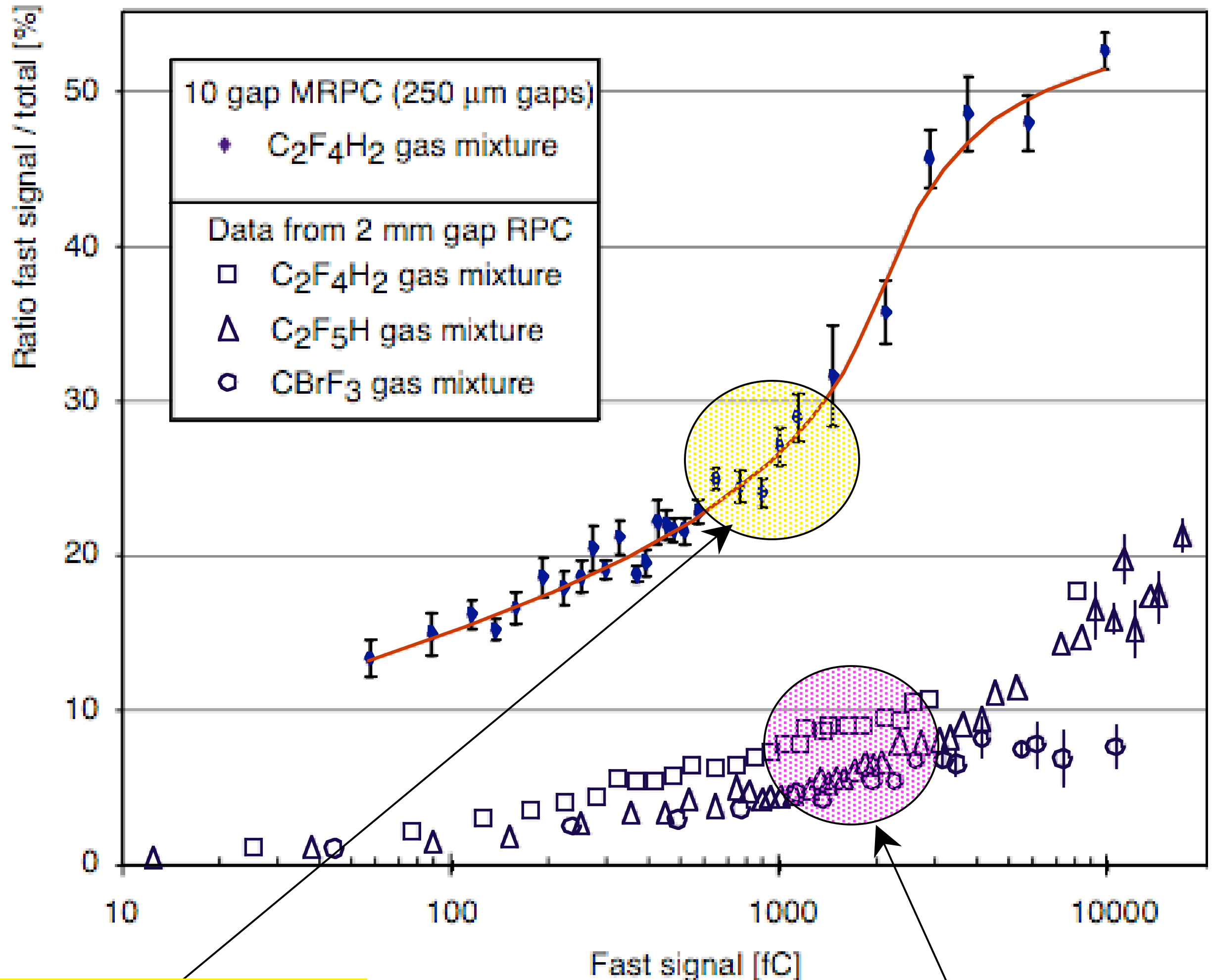
Ratio of fast signal/Total = 0.424/1.9 = 22 %



Ratio of fast signal/Total = 0.297/1.2 = 25 %



Ratio of fast signal/Total = 0.74/2.5 = 30 %



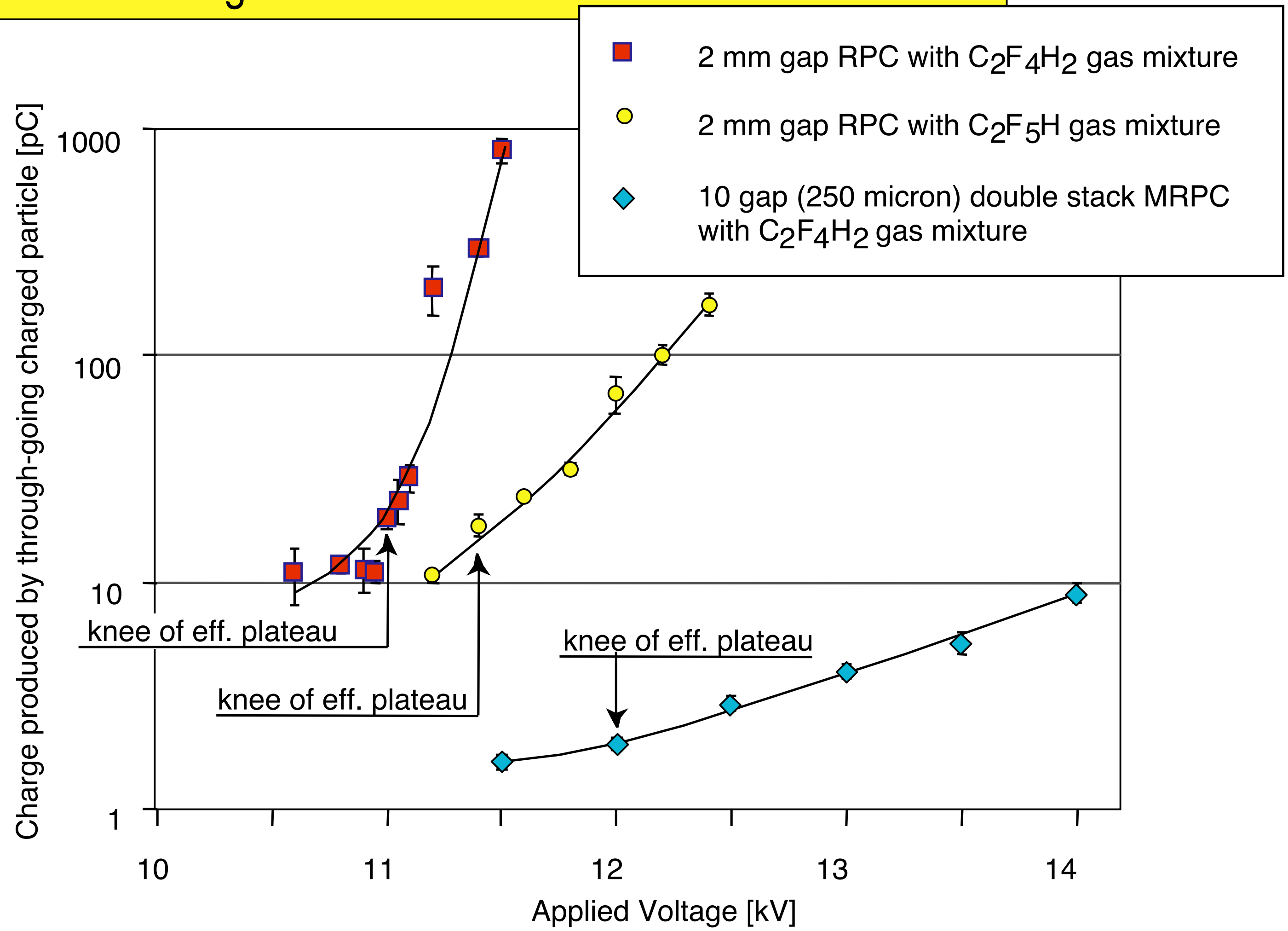
MRPC operates here!

Standard 2 mm gap RPC operates here

N.B. The increase of this ratio with increasing charge is a sign of space-charge limiting avalanche growth

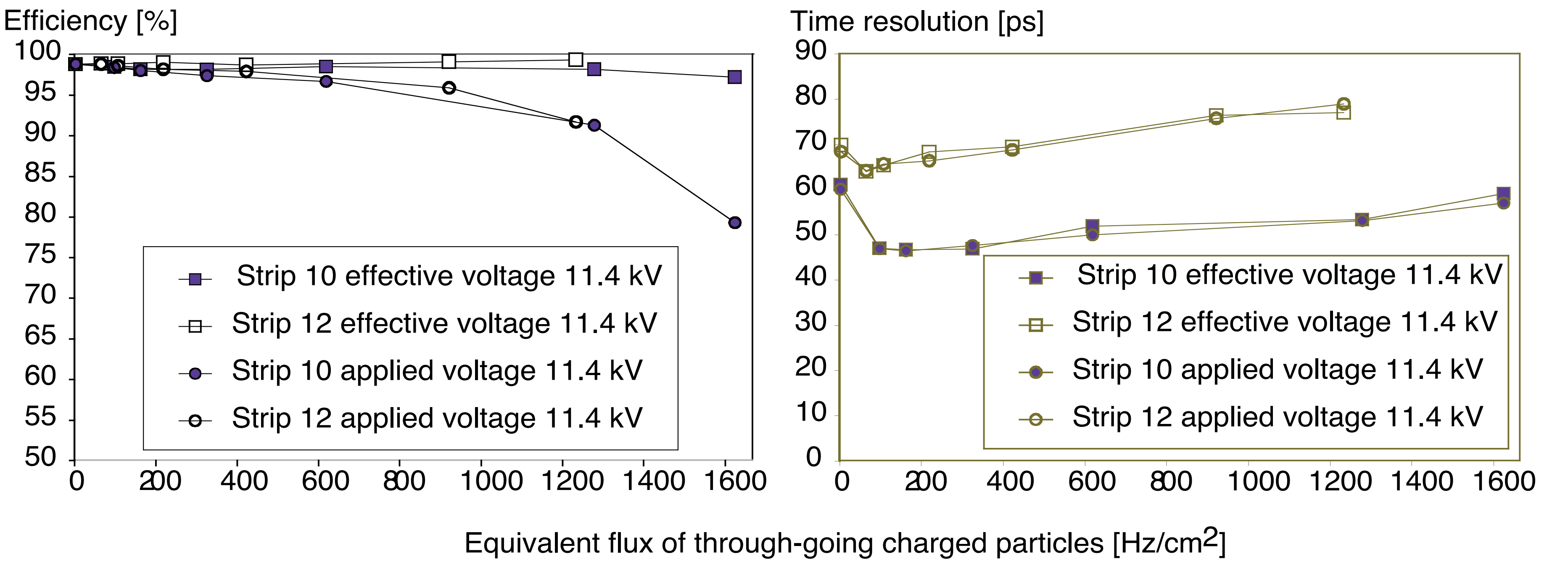
The next slide is important

Measure TOTAL charge of 2 mm RPC and ALICE-TOF MRPC



N.B.
(a) observe how slow gain changes with voltage (factor 5 / 2 kV)
(b) MRPC (ALICE TOF) average total charge ~ 2 pC (good rate capability)

Rate Capability

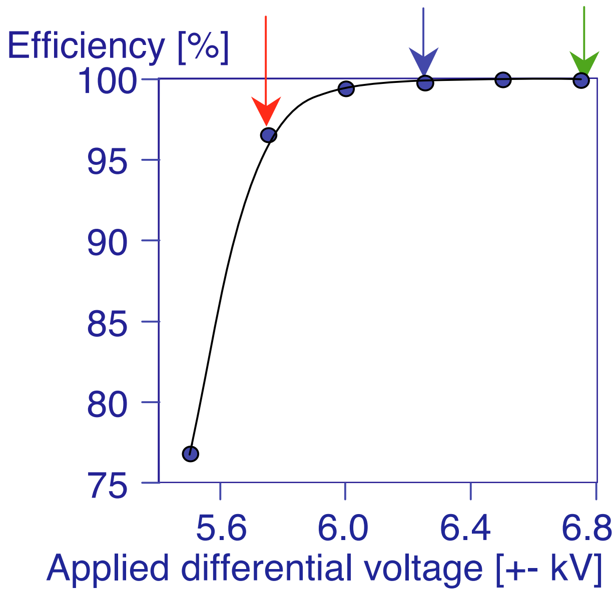


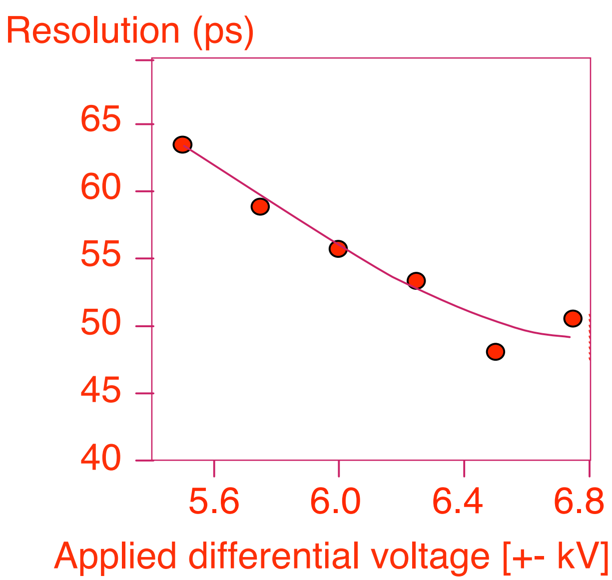
10 gap MRPC can be easily used up to continuous flux of 1 kHz/cm^2

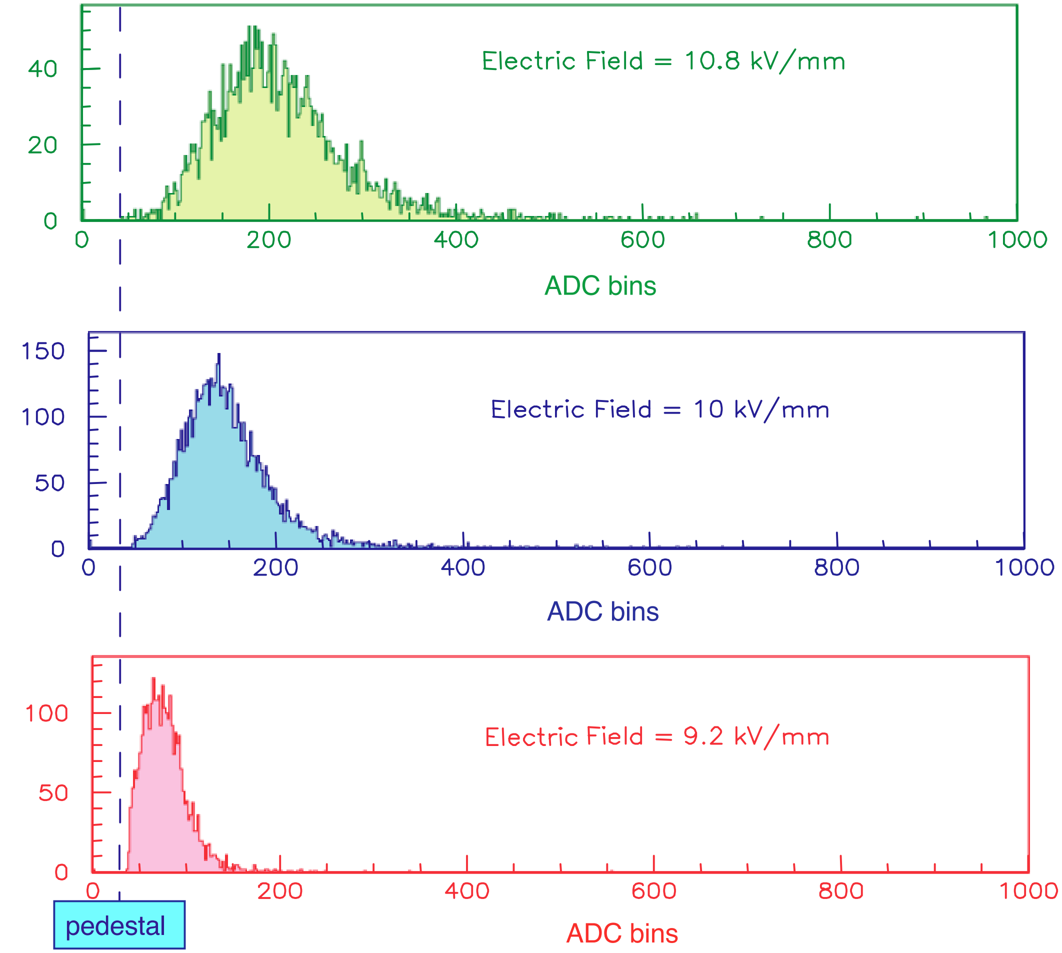
This good rate capability (for an RPC) due to small amount of charge generated by through-going particles.

Higher rate capability could be reached by using material with lower resistivity

Typical performance of MRPC designed for the ALICE TOF







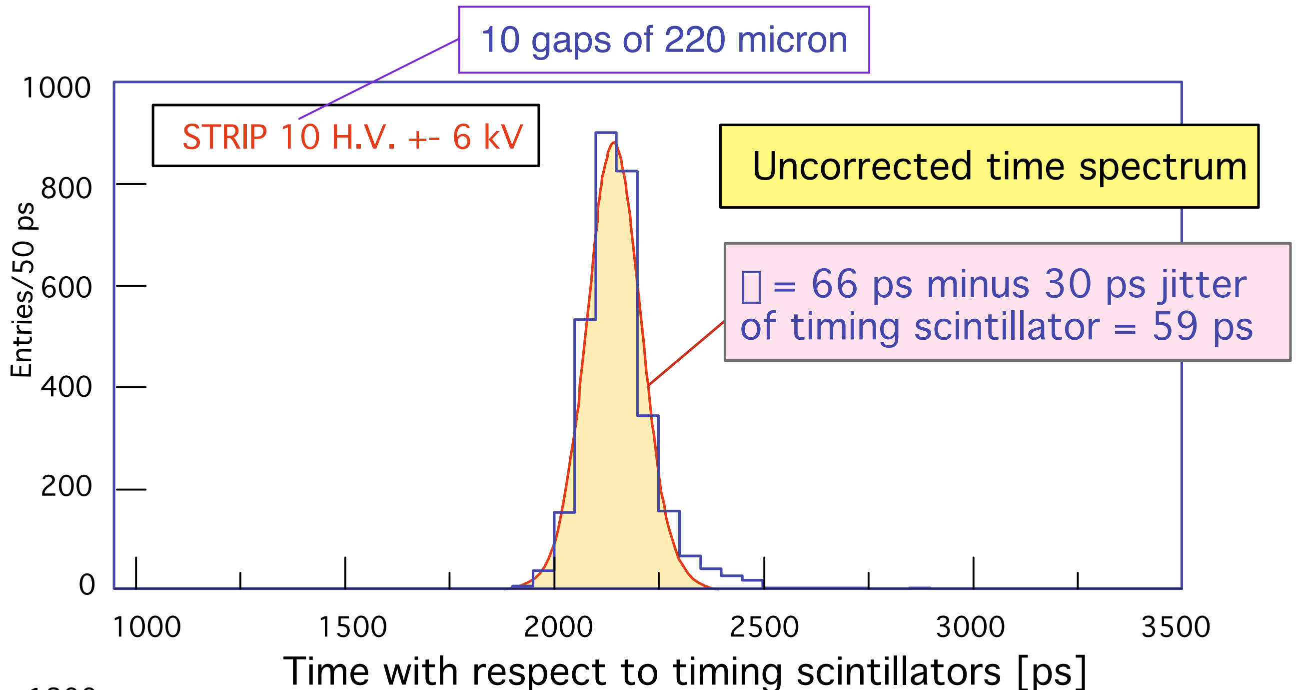
HIGHLIGHTS

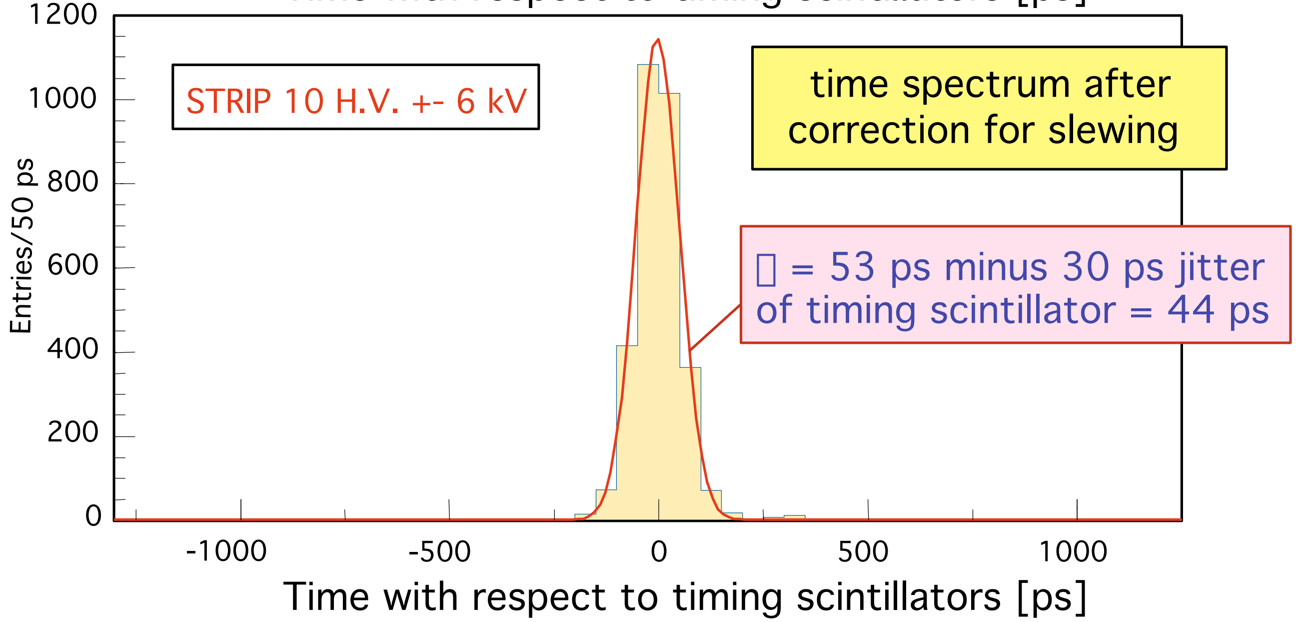
(a) Peak of charge spectra well separated from zero and almost gaussian in shape i.e. finite dynamic range - very important - allows us to minimise boundary effects.

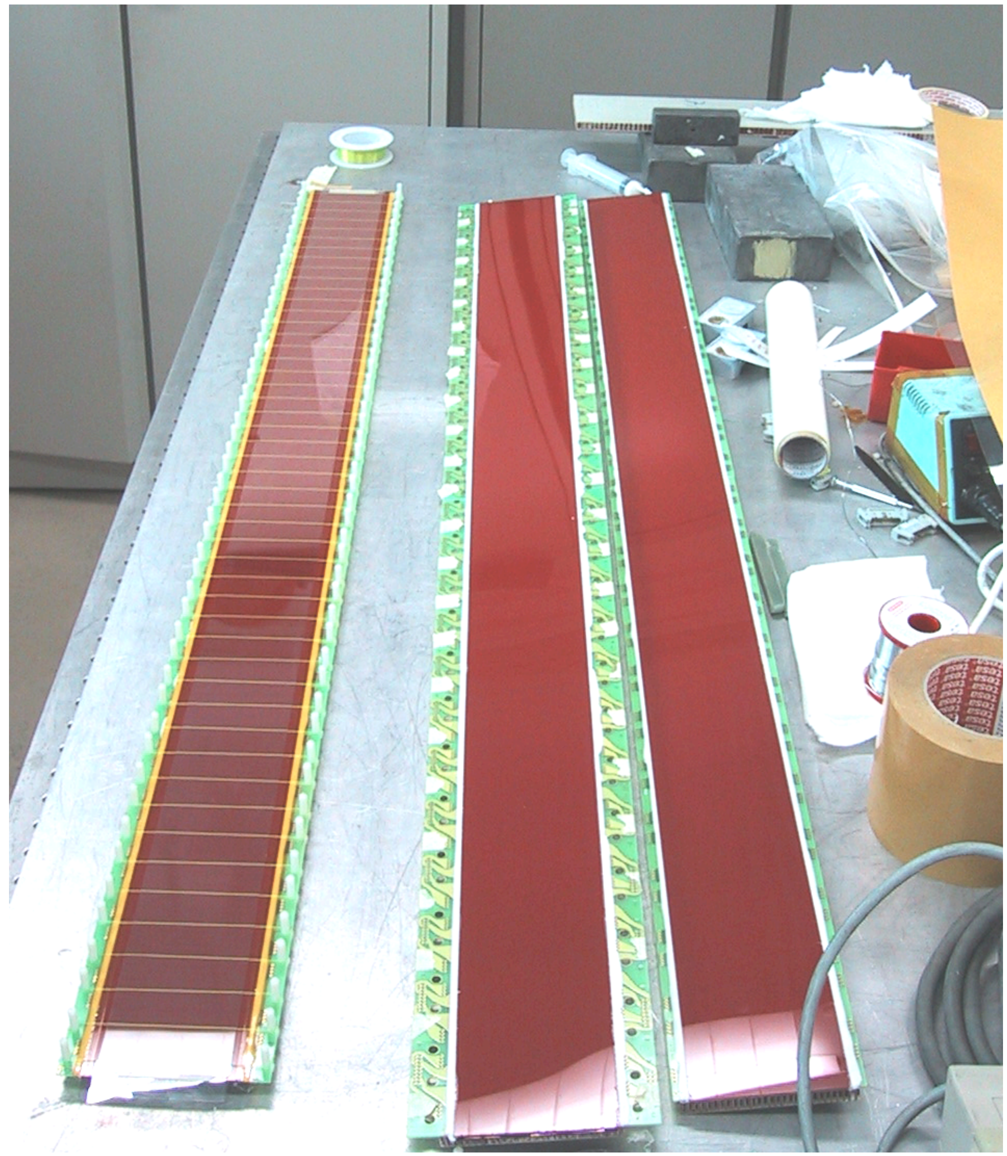
(b) No sign of streamers

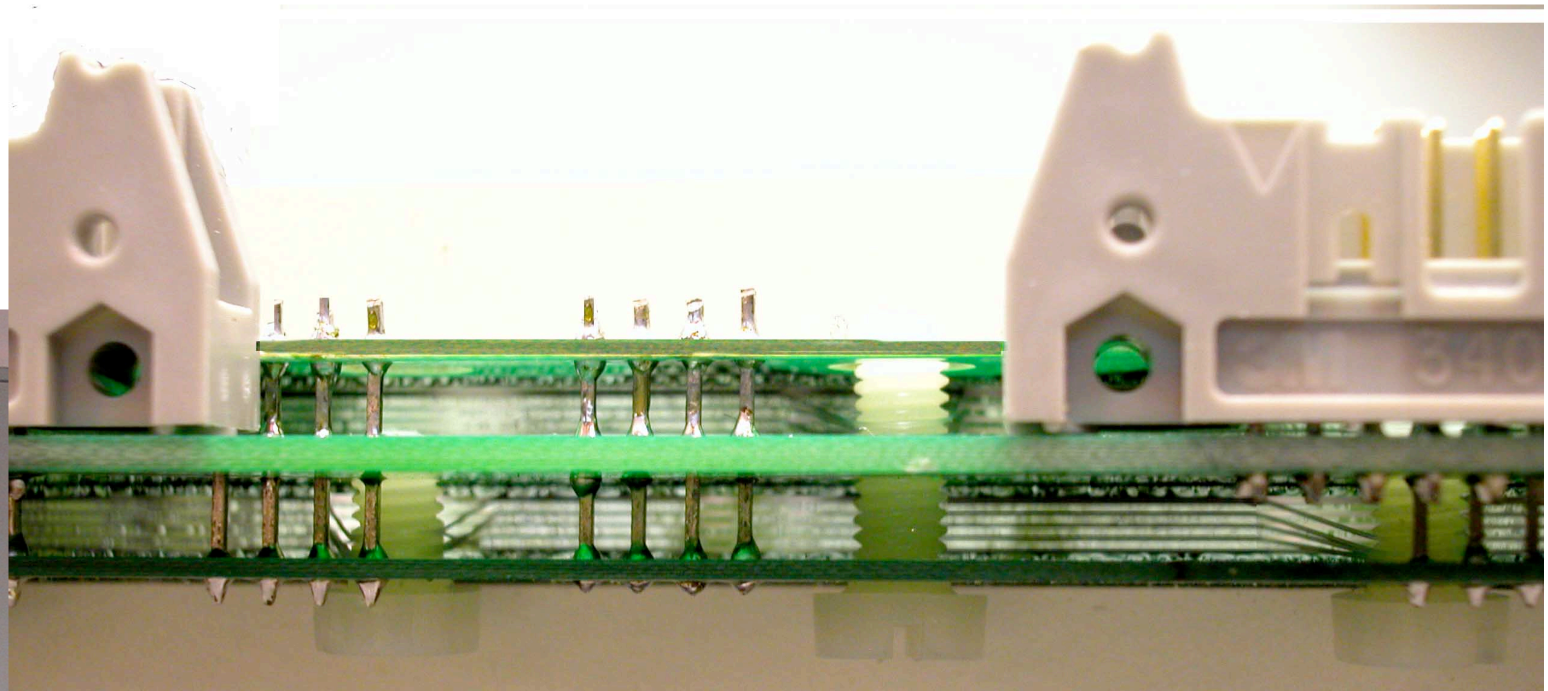
(c) Time resolution ~ 50 ps

Typical timing spectra







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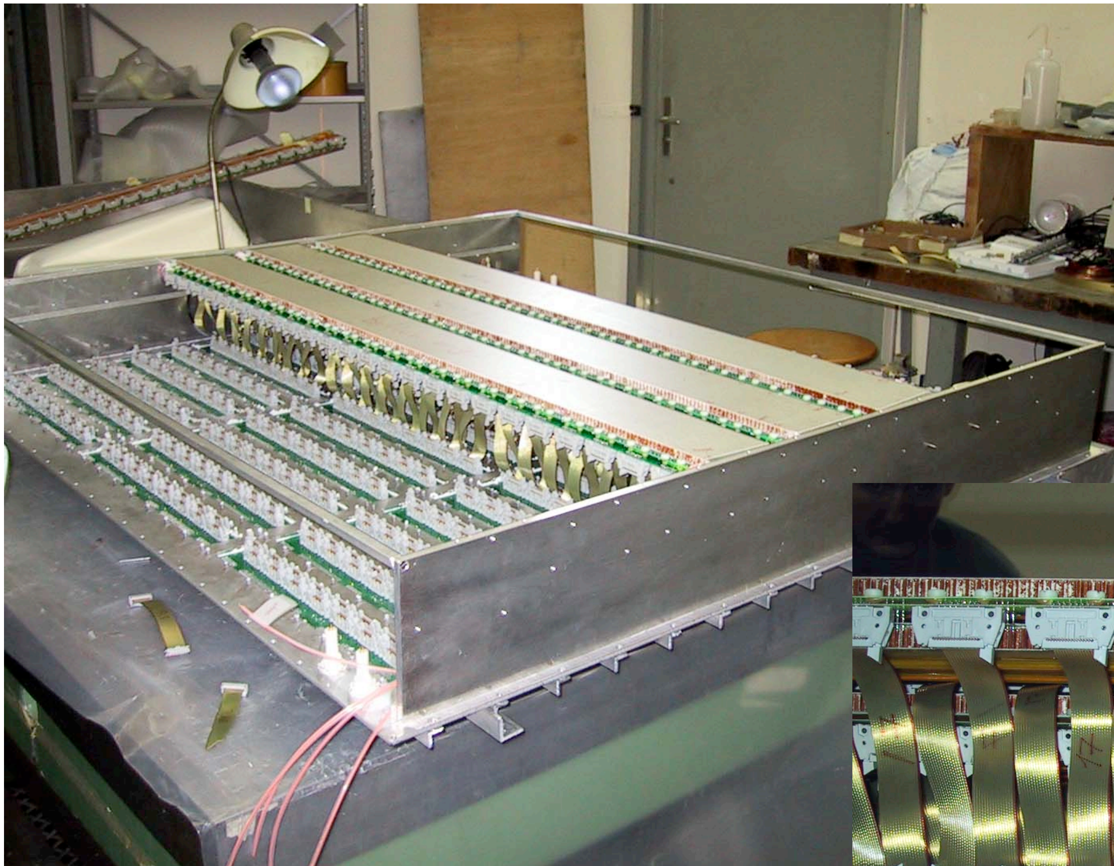

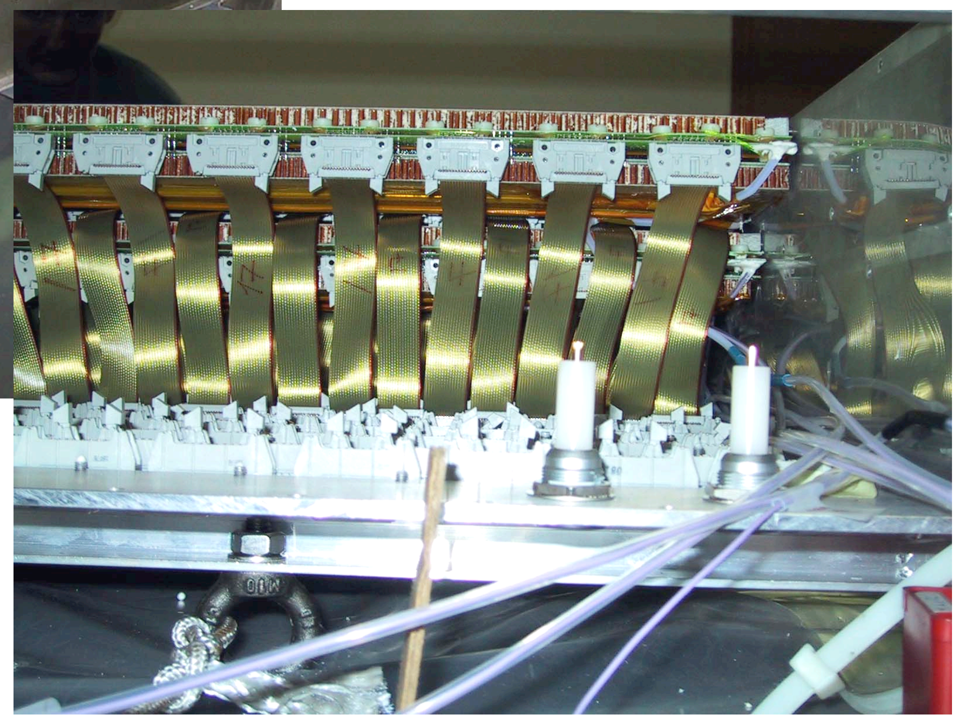

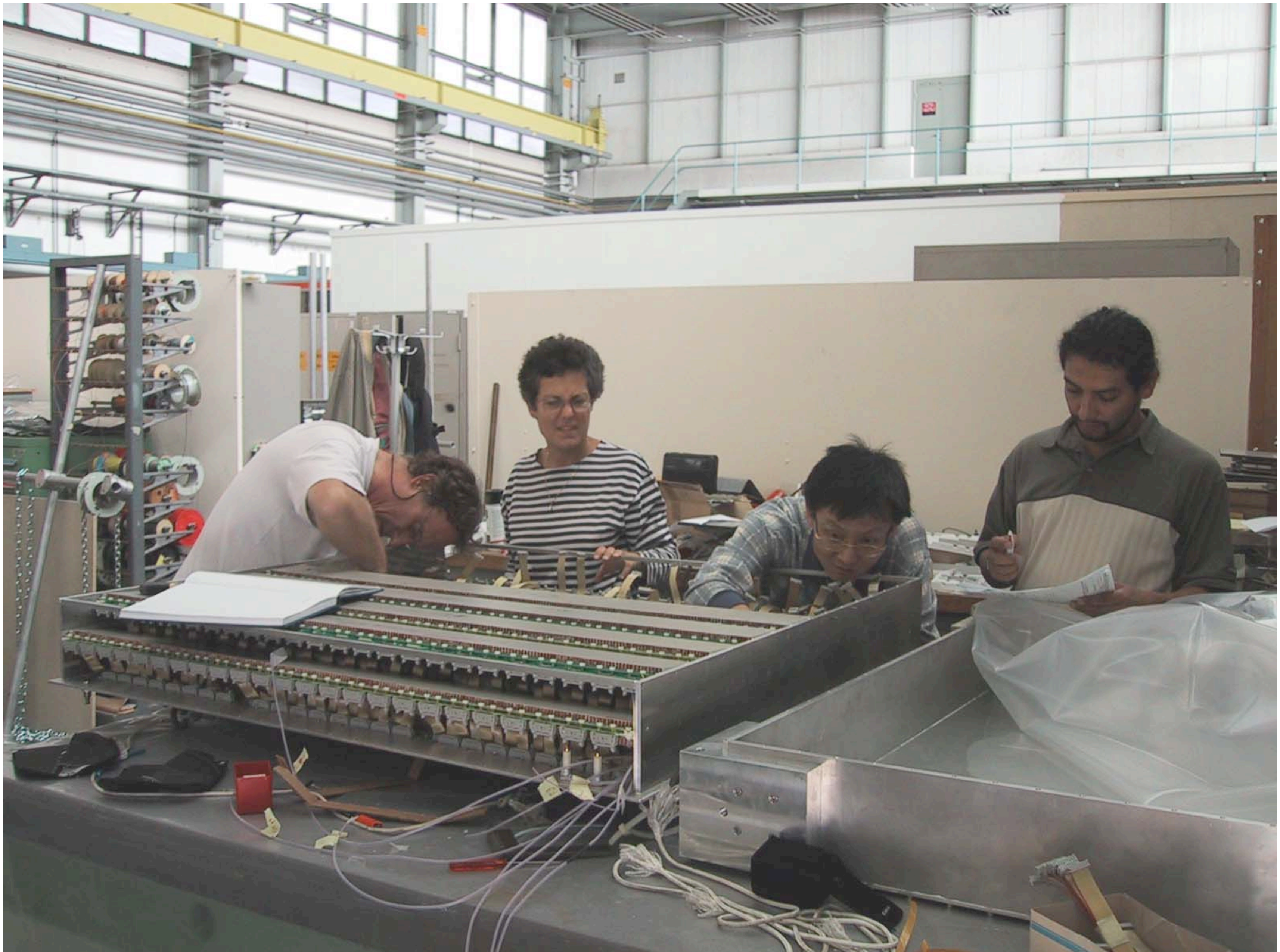

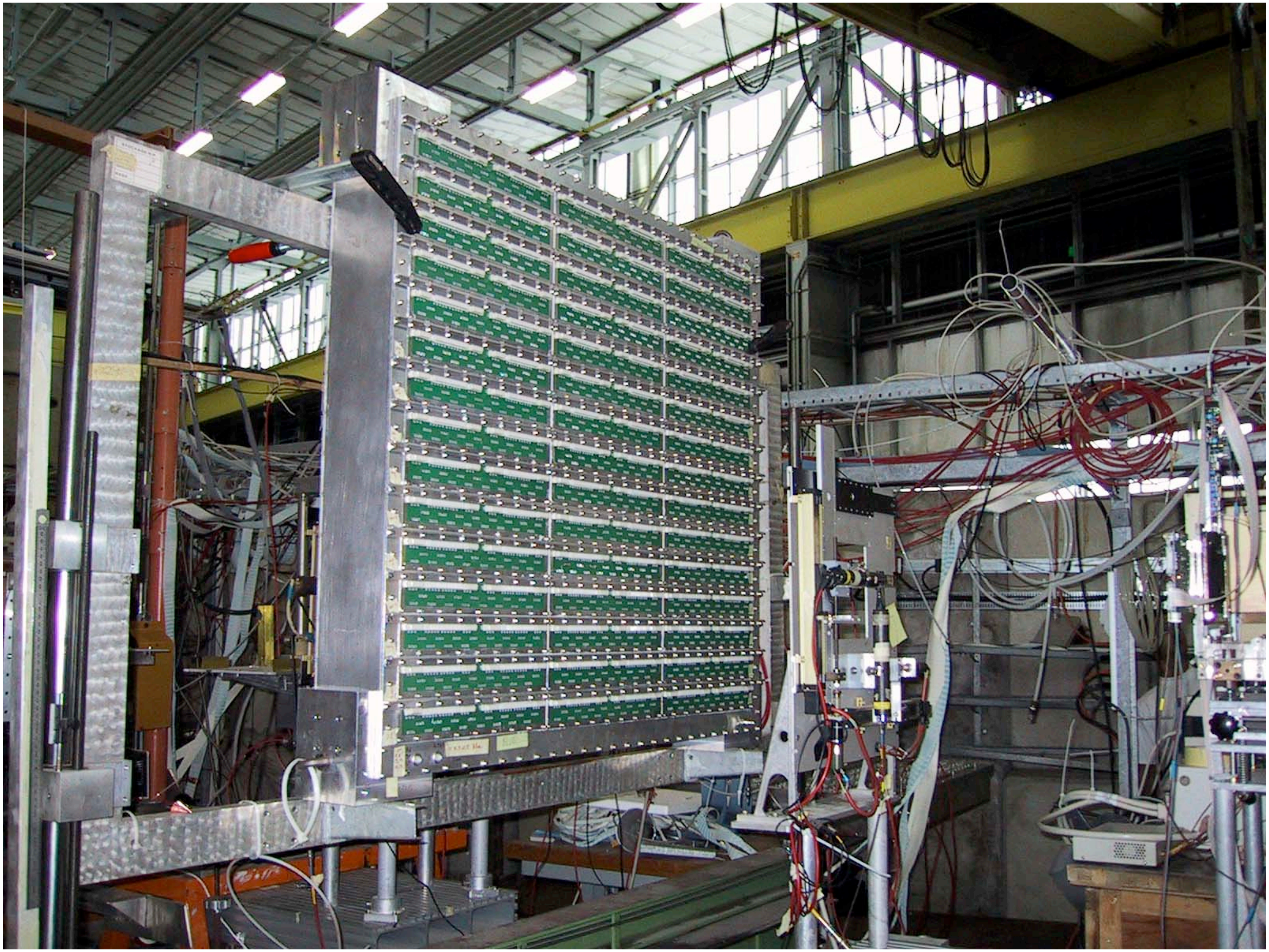

Summary

ALICE TOF array

150 m^2 160,000 channels

based on Multigap Resistive Plate Chamber

Long streamer-free efficiency plateau

Efficiency ~ 99.9 %

Time resolution ~ 50 ps

Space-charge limited avalanche growth

small change of gain with voltage

low total charge - therefore very excellent rate capability

Thank you for your attention